REMOTE SENSING APPLICATIONS IN FORESTRY

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A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

A Coordination Facility Administered Jointly By

The Pacific Southwest Forest and Range Experiment Station of the Forest Service, U.S. Department of Agriculture and by the School of Forestry, University of California

For

NATURAL RESOURCES PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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REMOTE SENSING APPLICATIONS IN FORESTRY

THE FEASIBILITY OF IDENTIFYING FOREST SPECIES AND DELINEATING MAJOR TIMBER TYPES IN CALIFORNIA BY MEANS OF HIGH ALTITUDE SMALL SCALE AERIAL PHOTOGRAPHY

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By

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ABSTRACT

Identification of forest species in California on high altitude small scale aerial photographs is possible when optimum photographic specifications are utilized. Recognizing tonal and morphological differences occurring between species is directly related to the following factors: film-filter combination, photographic scale, season of year, photo interpretation equipment, film exposure and film processing. Each of these factors has been analyzed and conclusions have been drawn as to the optimum specifications for identification of each of the species studied. A photo interpretation key for the identification of representative stands of several California species has been prepared utilizing aerial photography flown to optimum specifications.

AUTHOR

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Grateful acknowledgment also is given to personnel of Cartwright Aerial Surveys, Incorporated, who provided aerial photography to precise specifications so that valid comparisons could be made of photo images obtained by using various film-filter-scale combinations.

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by

Donald T. Lauer

INTRODUCTION

Aerial photographic interpretation has been established as an extremely useful aid to professional foresters. Rarely would the analysis of a forest resource not capitalize on the use of vertical aerial photographs. In western North America, a single district forester is frequently responsible for 250,000 to 500,000 acres of forest land. In less developed nations of the world, one man is often in charge of even larger land areas. With the proper aerial photographs, instruments and techniques a land manager can obtain more information in less time at a lower cost and with greater precision than he could without these aids.

Aerial photographs are used as a tool by professional foresters in many phases of land management, including forest inventory, road location, forest protection and damage assessment, reforestation planning, recreation site evaluation and planning, wildlife inventory, range land evaluation and watershed analysis. In most forestry operations, wood-producing trees are considered the most important land resource. However, a major problem confronts forest photo interpreters when evaluating a timber resource -- that of making an accurate identification of the species of individual trees or timber stands. The importance of accurate species identification comes to light when considering such factors as current timber prices (e.g. Pinus lambertiana, sugar pine, timber can be sold for approximately three times the price of Abies concolor, white fir), insect or disease susceptibility (e.g. Sequoia sempervirens, coast redwood, is much more resistant to insects and disease than in the associated species Pseudotsuga menziesii, Douglas fir), and recreation potential (e.g. a Sequoia gigantea, giant sequoia, stand may have greater value than all associated species in terms of its recreational potential).

The difficulties in pinpointing stand composition by species on aerial photos usually are due to inadequacies in one or more of the following factors: film-filter combination, photographic scale, season of photography, exposure and processing, photo interpretation equipment, or reference materials (photo interpretation keys).

Identification of individual tree species and stand types is feasible if the photo interpreter can recognize certain tonal and morphological differences occurring between various species. The interpretability of these differences is often directly related to the factors stated above. It is the objective of this research to analyze each of these factors (film-filter combination, photographic scale, season of photography, film exposure, film processing and photo interpretation equipment), and to determine the optimum combination of them for identifying several major tree types in selected parts of the world.

A descriptive key is provided in Appendix I, which illustrates the usefulness of aerial stereograms, terrestrial stereograms and schematic drawings as aids to the photo interpreter in identifying timber stands. Appendix II is an interpretation test to determine the extent to which the six major species occurring in the Sierra Nevada mixed conifer belt can be identified on low altitude, large scale aerial photography flown to optimum specification. Appendix III includes spectral reflectance curves of representative species studied in this report.

LITERATURE REVIEW

One of the first studies concerning the identification of tree species on aerial photography was made by Ryker (1933). It was known that the physiological structure of the leaves differs with species. Because of these structural differences, radiant light energy striking each species might be reflected differently. By filtering the reflected light rays, it was hoped that one species would photograph white, another black, and a third some shade of grey corresponding to the spectral characteristics of the reflected light.

Ryker concluded that the physiological characteristics of leaves are more a function of age or vigor of a tree than of its species. His study of 36 film-filter combinations prompted him to conclude that all the photographs taken with the infrared-sensitive film were of no practical value. Interpretation of the Super Pan film indicated that photographs taken through a green filter, which transmits only light with wavelengths of 460 to 620 millimicrons, were far superior to all the others. The study was limited primarily to large trees in open stands because crown shape as well as tone were used in identifying species.

Jensen and Colwell (1949) conducted a study on uses of aerial photography for forestry purposes in California A part of this project was to evaluate the relative merits of panchromatic minus-blue, panchromatic green and infrared minus-blue photography in identifying important timber species. Because the study was a part of the State project known as the Forest Survey, involving the inventory of all timber resources, two photographic scales were used. One was the smallest (1/20,000) capable of identification of general timber types. The other was the largest (1/15,000) that appeared economically possible.

Jensen and Colwell concluded that at a scale of 1/20,000 none of the film-filter combinations consistently provided tonal or other distinctions between the important timber species except partial separation between pine and fir on panchromatic film.

The larger scale (1/15,000) provided partial separation of Pinus lambertiana (sugar pine) from Pinus ponderosa (ponderosa pine) on panchromatic minus-blue but not on infrared minus-blue photography. The determining factor was an evident branching habit rather than a tonal difference. No additional gain could be found on the panchromatic green.

At the scale of 1/15,000 or smaller, species identification must be made almost solely on the basis of tonal differences. Tree configuration cannot be resolved at these scales,assuming a resolution on the aerial negatives of no better than 30 line pairs per millimeter. However, it would seem that little reliance could be placed on the photographic tone of a tree when the tone is influenced by such factors as chlorophyll content of foliage; size, shape, density and orientation of leaves; position of tree within the stand; site; slope; sun angle; atmospheric conditions and position of tree image on the photograph relative to the photo center.

At larger scales, greater reliance can be put on minute photo detail,and tree phenological characteristics become the determining factors in species identification. Jensen and Colwell observed no instances where infrared minus-blue gave greater clarity of detail than the panchromatic combinations. The authors found no appreciable differences in photo detail between panchromatic minus-blue and panchromatic green at scales of 1/15,000 and 1/20,000.

Several authors consider it dangerous to generalize results of one region to another when selecting the proper film-filter combination for determining species composition

On the west coast where conifer stands are the dominant species, panchromatic photography was considered better. In the east it is necessary to distinguish hardwoods and conifers which occur in about equal quantities in many forest regions. Spurr and Brown (1946), Seeley (1949) and Sonley (1946) concluded that in the east, where hardwood trees and coniferous trees may have remarkable similar form, infrared film with a minus-blue filter (the so-called "modified infrared" photography) is effective in providing a tonal separation between hardwoods and conifers. It is less valuable than panchromatic photography, however, for certain other purposes (e.g. telling individual species of hardwoods and conifers). In the Great Lakes states, Chase and Korotev (1947) and Steigerwaldt (1948) preferred infrared with a minus-blue filter. In anchorage, Alaska, Stone (1950) used panchromatic photos successfully Raup and Denny (1950) used "modified infrared" photography for interpreting the vegetation and terrain in British Columbia

Schulte (1951) compared the use of panchromatic, infrared and color aerial photography in the study of plant distribution in southeastern Canada Of the three film types, infrared was considered preferable and panchromatic and color about equal for recognizing plant species.

Sayn-Wittgenstein (1961) studied the importance of crown characteristics for tree species recognition as a function of photographic scale. He gave special consideration to the value of phenology and ecology in species identification. The aerial appearances of 24 species were described in detail and elimination keys were provided for the identification of these species on large scale aerial photographs.

The area examined was near Ottawa, Canada and consisted of 9 species of conifers and 15 species of hardwoods. Panchromatic photography was flown at large and medium scales. It was found on scales of 1/600 that most species can be recognized almost entirely by their morphological characteristics At scales of 1/2,500 small and medium branches are still visible and at 1/7,500 individual trees can still be separated, except when growing in dense stands. However, this scale is no longer suitable for exact species identification, again assuming a photographic resolution of no better than 30 line pairs per millimeter.

Emphasis was placed on visual aids in developing an elimination key Schematic drawings of typical tree forms, in both the terrestrial and overhead views, preceded a detailed word description of the tree's appearance. A knowledge of the ecological and silvicultural characteristics of species proved to be of great value in developing the word description. Accompanying each description was an aerial stereogram illustrating the particular species and its determining characteristics.

Zsilinszky (1962) in applying photo interpretation to a forest inventory emphasizes that the accuracy of photo interpretation depends upon both the quality of the photography and the ability of the photo interpreter. Selection of the aerial photographic specifications is based essentially upon the purpose of the forest survey and is affected by such factors as season, climate, sun angle, equipment, materials and procedures.

He found that the information extracted from photos is directly related to the skills of the photo interpreter and the optical aids used. Since the photo interpreter must be familiar with the subject matter, foresters and forest technicians should be employed as interpreters. Both intensive training and periodic testing must precede operational interpretation.

Species interpretation is very difficult unless proper tree image illumination is provided. In discussing optimum lighting conditions, Zsilinszky found that "back lighting" of tree images proved to be advantageous over "front lighting". Position of the tree image with respect to the center of the photo and the direction of the sun's rays also must be considered.

Crown shape and texture, forest stand pattern, and photographic tone are the image characteristics most commonly used in tree identification. Zsilinszky presented schematic illustrations of characteristic crown shapes in both horizontal and vertical view.

Heller, Doverspike, and Aldrich (1963) reported on the results of research conducted in Minnesota concerning identification of tree species on aerial photographs. Comparisons were made between large scale panchromatic and color aerial photographs and conclusions were drawn as to the best film-filter-scale combination for species identification.

Fourteen important species were selected for study and were photographed on Super Anscochrome and Plus X Aerographic films at average scales of 1/3,960, 1/1,584 and 1/1,188.

Interpretation results indicated that identifications made on color transparencies were significently more accurate than those made on black-and-white prints. Interpretation accuracy increased with scale on both films, but for the color transparencies, the two larger scales were almost equally accurate.

An evaluation of tonal differences between tree species was made by Hindley and Smith (1957) in British Columbia. Since the tone of an object as seen on an aerial photograph is directly affected by the amount of light reflected from it in the wavelengths exposed for, reflectance of coniferous foliage was studied. Reflectance measurements were made of nine species with a Beckman model DU spectrophotometer.

The studies revealed wide variations in reflectance within species. It was concluded that improved tree species identification will come from better knowledge of tree shape and habit rather than from emphasis of tonal differences through varying film-filter combinations.

Seasonal changes in light reflectance of tree species were studied by Olson and Good (1962). Light reflectances from the foliages of nine tree species found in Illinois were measured weekly with a G.E. recording spectrophotometer.

It was found that hardwood foliage reflected more light than coniferous foliage in almost all wavelengths during all parts of the growing season. There was a slight increase in reflectance found in the conifers throughout the growing season as new needles reflected more light in comparison to one-year-old needles. Considerably greater variations were found in reflectance from hardwood foliage than from coniferous foliage. Hardwood leaf reflectance steadily decreased until fall coloring occurred. A tremendous increase in reflectance, with great variation between species, was observed as fall coloring commenced.

It seemed logical that the probability of obtaining distinct tonal contrast between hardwoods and conifers on panchromatic photography would be greater in the early and late stages of the growing season than in mid-summer. The examination of existing aerial photography supported this presumption.

In addition to the studies listed, a considerable amount of work has been performed in areas outside North America pertaining to the inventory of forest species composition. Studies by Miller (1960) in British Honduras concluded that in the tropics only groups of trees can be distinguished on aerial photography rather than individual species. Photography flown at a scale of 1/30,000 and smaller does provide much useful information, however.

Francis and Wood (1956) described 16 vegetation types that could be identified on photos at scales from 1/25,000 to 1/30,000 in northern Borneo.

In Uganda, Cahusac (1957) studied the feasibility of mapping forest types on 1/30,000 to 1/40,000 photography and points out that six individual species could be recognized.

JUSTIFICATION FOR CURRENT RESEARCH

Studies analyzing the various aspects of tree species identification on aerial photographs have been performed by competent authors throughout the United States, Canada and other parts of the world. One basic fact is evident from a review of these studies: it is very dangerous automatically to apply the findings from one geograpnical area to another. Different geographical areas on the surface of the earth vary, not only in tree species composition, but also in ecological and silvicultural characteristics. What is concluded about a southern pine forest may not be applicable to a northern alpine forest; an eastern hardwood forest obviously will appear quite different than a central Sierra Nevada mixed conifer forest.

Selection of optimum film-filter combinations has generally been done on a trial and error basis; few studies have attempted to correlate spectral reflectance data with tone signatures from spectrozonal photography to aid in this decision process. Also, the merits of color and color infrared (false color) films have not been adequately investigated.

There is a definite lack of data pertaining to the evaluation of high altitude, small scale aerial photography for identifying any particular species or group of species. In relation to the definition of the manned earth-orbital experiment program, this research is needed as a first step toward determining the extent to which timber surveys might eventually be made from manned earth-orbital vehicles.

Descriptive photo interpretation keys based on aerial photographs flown to optimum specifications would be useful aids to forest photo interpreters throughout the world, even though a separate key probably would be needed for each region. Such keys, if properly constructed, could be used either for general forest inventory purposes or for more concise purposes such as the evaluation of insect-induced mortality in timber stands. No matter what objective is desired, such guides for determining tree species accurately on high altitude vertical aerial photographs would prove valuable.

EXPERIMENTAL METHODS AND PROCEDURE

1. USGS topographic maps were obtained of the two test sites wherein this investigation was to be conducted; namely, the Meadow Valley-Bucks Lake area in the central Sierra Nevada (mixed conifer forest type) and the San Pablo Reservoir area in the Coast Range (chaparral-hardwood forest type). See Figure 1.

2. Flight lines were drawn on these maps so as to provide complete aerial photographic coverage of the two test areas at both large (1/10,000) and small (1/30,000) scales.

3. On June 6 and 7, 1965, the Houston-based NASA remote sensing Convair airplane flew the prescribed flight lines at both scales with the following film-filter combination: Aerial Ektachrome (E-3) film with no filter, Ekta Aero Infrared film with a Wratten 12 + EF 2200 filter, Pan-

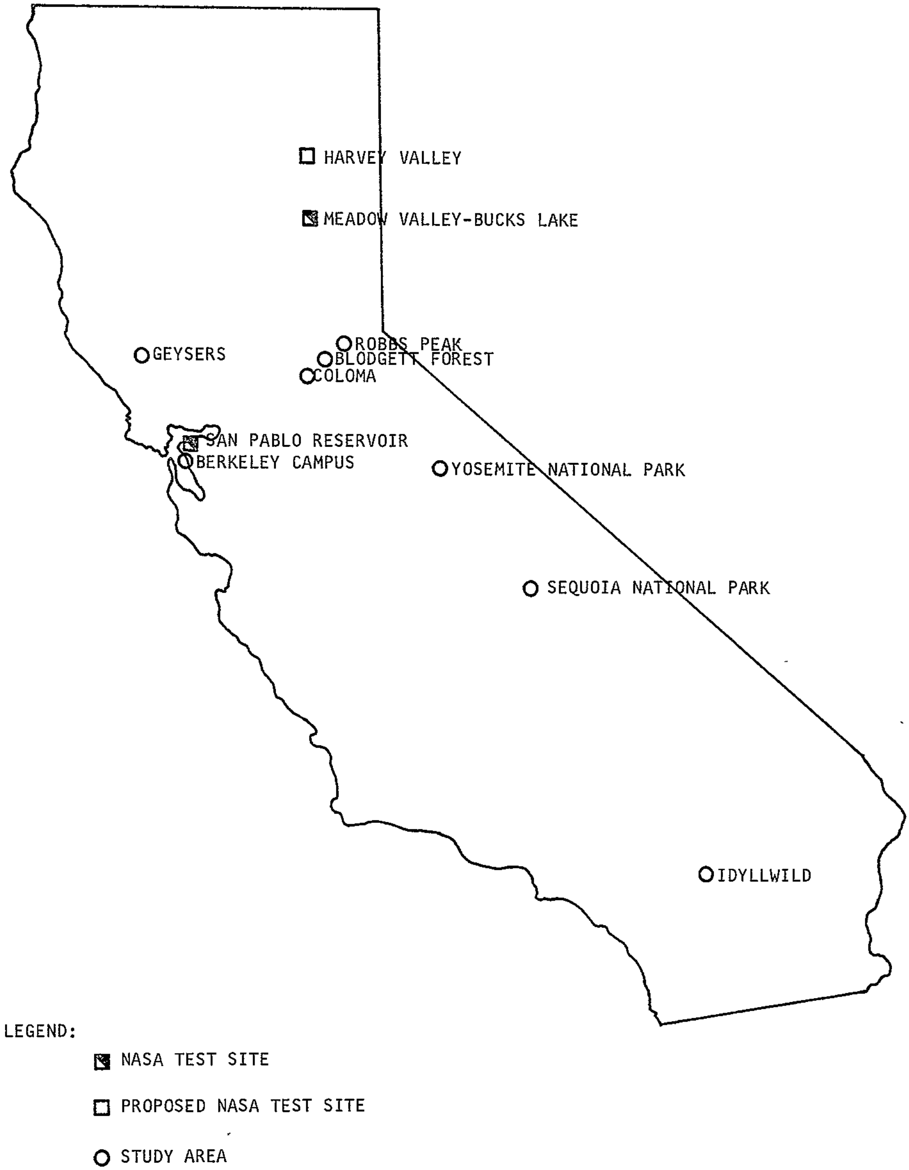


Figure 1: Sites in California wherein this investigation was conducted. The majority of the study areas occur in the Sierra Nevada (mixed conifer forest type) or in the Coast Range (chaparral-hardwood forest type).

chromatic Plus-X Aerographic film with a Wratten 12 filter, and Infrared Aerographic film with a Wratten 89B filter. (Additional aerial coverage, large and small scale, was obtained of these two test sites, plus alternative study areas, through cooperative agreements with other agencies).

4. With the large scale aerial photography in hand, field crews established the location of "pure stand" field plots of each timber type that occurs in each of these areas. Where possible, each timber type was replicated with three field plots. The plots were chosen on the basis of stand composition, density, size and accessibility.

5. Thirty-nine "pure stand" field plots were established in the Meadow Valley-Bucks Lake area and twenty-one plots were established in the San Pablo Reservoir area.

6. The following "pure stand" timber types were found to occur in the Meadow Valley-Bucks Lake area:

(a) Conifers: <u>Pinus ponderosa</u> (ponderosa pine); <u>Pinus contorta</u> (lodgepole pine); <u>Abies magnifica</u> (red fir); <u>Abies concolor</u> (white fir); <u>Pseudotsuga menziesii</u> (Douglas fir); <u>Libocedrus decurrens</u> (incense cedar) and mixed conifer (p. pine, s. pine, w. fir, D. fir, and i. cedar).

(b) Hardwoods: <u>Quercus kelloggii</u> (California black oak); <u>Acer macrophyllum</u> (big leaf maple); <u>Populus trichocarpa</u> (black cottonwood); <u>Alnus tenuifolia</u> (alder); <u>Populus tremuloides</u> (trembling aspen); <u>Salix sp.</u> (willow) and <u>Cornus nuttallii</u> (dogwood).

7. The following "pure stand" timber types were found to occur in the San Pablo Reservoir area:

(a) Conifers: <u>Pinus radiata</u> (Monterey pine).

(b) Hardwoods: Eucalyptus globulus (blue gum eucalyptus); Quercus agrifolia (coast live oak); Umbellularia californica (California bay); Salix sp. (willow); Aesculus californica (buckeye); and mixed hardwood (big leaf maple, madrone, buckeye, coast live oak and California bay).

8. The following information was recorded for each of the field plots: stand composition, understory description, stand age (overmature, mature, intermediate, young), average tree height, range in tree height, average diameter at breast height, range in tree diameter at breast height, aspect, average (percent) slope and range in percent slope.

9. Soil types were examined and identified and soil moisture relationships were recorded for each of the field plots.

10. During the midsummer seasonal state, four 35 mm cameras were employed in taking stereo pair terrestrial photographs of each of the field plots. The following four film-filter combinations were used: Kodak Kodachrome II film with no filter, Kodak Ekta Aero Infrared film with a Wratten 12 filter, Kodak Panchromatic Plus-X film with no filter and Kodak Infrared film with a Wratten 89B filter.

11. Each of the field plots was visited periodically during the fall seasonal state. Again, 35 mm stereo pair photographs were taken and the autumn seasonal changes and foliage colorations were recorded with the four film-filter combinations.

12. On September 28 and 29, 1965, the NASA Convair again flew the two test areas with the same film-filter combinations and at the same photographic scales as stated in (3). In addition, nine-lens multiband imagery was flown of the San Pablo Reservoir area.

13. Upon receiving this imagery late in October, a field crew made an on-the-ground check, with photos in hand, of interesting areas located outside established field plot boundaries.

14. From each of the "pure stand" field plots, foliage samples were obtained with the aid of an 18-foot tree trimmer. The samples were mounted between clear glass plates, placed under refrigeration and transported to the Electrical Engineering Laboratory of the University of California at Richmond, California. Each sample's spectral reflectance characteristics were then measured, wavelength by wavelength, with a G.E. laboratory recording spectrophotometer throughout the entire range for which that spectrophotometer is operative (400 to 1000 millimicrons). The spectral range of this instrument covers virtually all of the spectrum in which photographic images can be obtained directly on film emulsions by means of remote reconnaissance. Hence, it gave information highly pertinent to the present study.

15. The spectrometric analysis and the aerial photographic mission were conducted simultaneously, both in June and in October.

16. With the aid of accurate ground truth obtained for the "pure stand" field plots, all high altitude small scale photography has undergone intense interpretation. For each species, aerial photo recognition features such as stand color or tone, texture and morphology have been analyzed.

17. Correlations have been made between spectrometric curves of the vegetation types and color or tone signatures of these types as imaged on the various film-filter combinations.

18. The value of sequential aerial photography in exploiting seasonal changes in vegetation has been determined by correlating sequential

terrestrial photography with the two sets of aerial photography.

19. Correlations between understory vegetation, soil type and overstory vegetation have been made.

20. Using all pertinent information derived from the above analysis, dichotomous aerial photo interpretation keys for the timber species examined in this study have been made for both the central Sierra Nevada mixed conifer forest type and the Coast Range chaparral-hardwood forest type.

21. Evaluation of multiband (ultraviolet, visible, near infrared and thermal infrared) imagery of forest types in Yosemite Valley has been made. This imagery was taken from a stationary position atop Glacier Point during the period June 20-24. The thermal infrared imagery was taken with a thermographic camera provided by Barnes Engineering Co., Stamford, Connecticut.

22. To a limited extent, and depending upon the availability of aerial photography, findings in the Meadow Valley-Bucks Lake area and the San Pablo Reservoir area have been tested on similar tree species in the Sierra Nevada Mountains and Coast Range of California.

MEANS OF IDENTIFICATION

The ability of a photo interpreter to identify tree species in a forest stand depends primarily on three characteristics governing the quality of the photographic images: (a) tone contrast, (b) image sharpness, and (c) stereoscopic parallax.

In the analysis of high altitude small scale photography (simulating an enlargement of the type of imagery that might be obtained from a reconnaissance satellite), the primary means of identification of forest stands is by tone contrast (i.e. the difference in tone or brightness between an image and its background). Lens aberrations and the limited resolving power of film emulsions prevent the use of image sharpness in recognizing stand form and structure. Due to the adverse ratio of flying height to tree height, stereoscopic parallax is very small on satellite photography. The displacement of the apparent position of the tree crowns caused by a shift in the point of observation, 100 miles or more above the earth's surface, cannot be resolved by the system, even on photos taken with the maximum "stereo base-to-flying height" ratio. By convergence of evidence, surrounding ecological and silvicultural patterns provide aids of secondary value for the identification of timber stands, however.

The manipulation of aerial photographic specifications can affect considerably the ease of identifying forest stands by altering the apparent tonal and morphological characteristics.

Photographic Tone

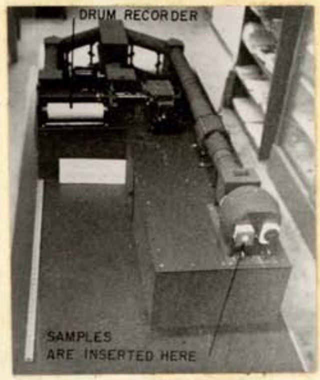
The photographic tone or color of a tree is an expression of the spectral reflectance from it, the spectral sensitivity of the film, the spectral transmittance of the filter and the spectral scattering by atmospheric haze particles.

Film-Filter: In order to determine an optimum film-filter combination for recognizing tree species through tonal differences, the spectral reflectance characteristics of the subject being photographed must be thoroughly understood. Several papers have been written on the spectral reflectance characteristics of tree types growing in specific areas throughout North America (Hindley and Smith, 1957; Olson and Good, 1962). It was generally concluded that spectral reflectance of tree foliage varied more within a particular species than between species. The variation was found to be more a function of a tree's vigor, topographic site, etc. than of its species. Yet, when interpreting large timber stands on small scale photos, stand tone is a composite of individual tree variation and there is a greater likelihood that this composite tone will be unique for a particular species.

In the present study, foliage samples were taken from representative species studied and light reflectance curves for these samples were obtained with a G.E. electrical recording spectrophotometer (see Appendix III). Figure 2 shows a summary graph of reflectance data for each of three timber species which occur in the mixed conifer belt of the west side Sierra Nevada mountains.

The curves shown in Figure 2 indicate a pronounced variability in reflected light between the three species studied. This variation allows the possibility of gaining additional information by sensing photograhy in a single band or combination of bands of the spectrum. Libocedrus decurrens (incense cedar) consistently reflects a greater percentage of light throughout the visible spectrum than do the other two forest species. This difference in reflectance is most apparent in the 500 to 600 millimicron range of the spectrum. Cornus nuttallii (mountain dogwood) reflects a greater amount of near infrared light (700 to 1000 millimicrons) than the other two species, while Pseudotsuga menziesii (Douglas fir) has a relatively low degree of light reflectance throughout the photographic

Leaf samples of Libocedrus decurrens (incense cedar) mounted between clear plates.



G.E. Laboratory Recording Spectrophotometer

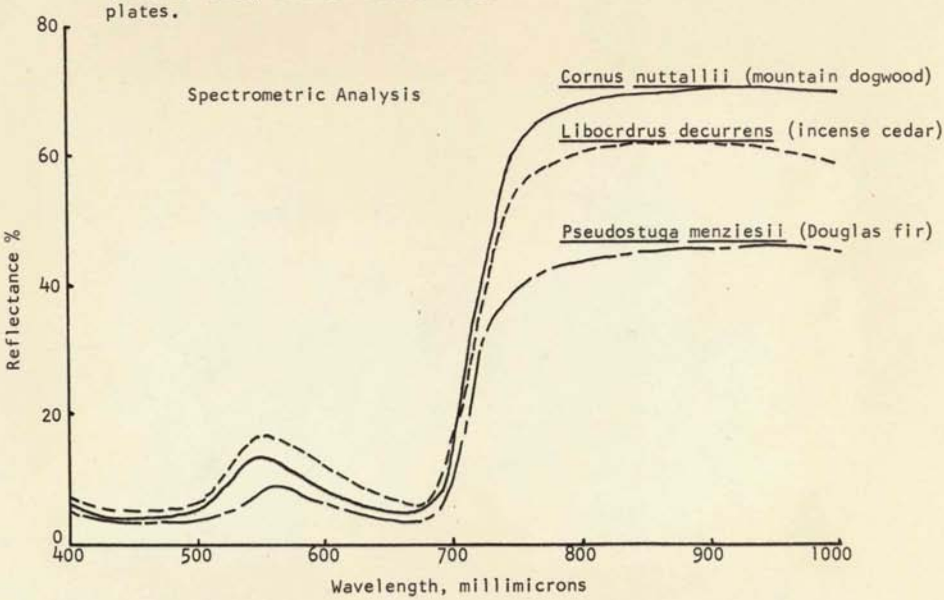


Figure 2: To avoid sample deterioration, these spectral measurements were made on living needles mounted between clear glass plates. Compare the reflectance data of these three species with the multiband photos shown in Figure 3.

Film: Kodachrome II
Filter: None
Sensitivity: 400-700 millimicrons

Film: Ekta Aero Infrared
Filter: Wratten 12
Sensitivity: 510-900 millimicrons

Film: Panchromatic
Filter: None
Sensitivity: 400-700 millimicrons

Film: Infrared
Filter: Wratten 89B
Sensitivity: 700-1000 millimicrons

Figure 3: Pronounced variability in reflected light between these three species (see Figure 2) allows the possibility of gaining additional information by taking photography in a single band or combination of bands of the spectrum.

Film: Panchromatic
Filter: #3 9-lens camera
Sensitivity: 500-600 mμ

Film: Panchromatic
Filter: #6 9-lens camera
Sensitivity: 640-720 mμ

Film: Infrared
Filter: #7 9-lens camera
Sensitivity: 690-830 mμ

Legend: _Pinus radiata_ (Monterey pine) ———————— A
Umbellularia californica (Calif. bay) - - - - - - - - B
Rhus diversiloba (poison oak) — — — — — — — C
Baccharis pilularis (Coyote brush) ——— - ——— - — D

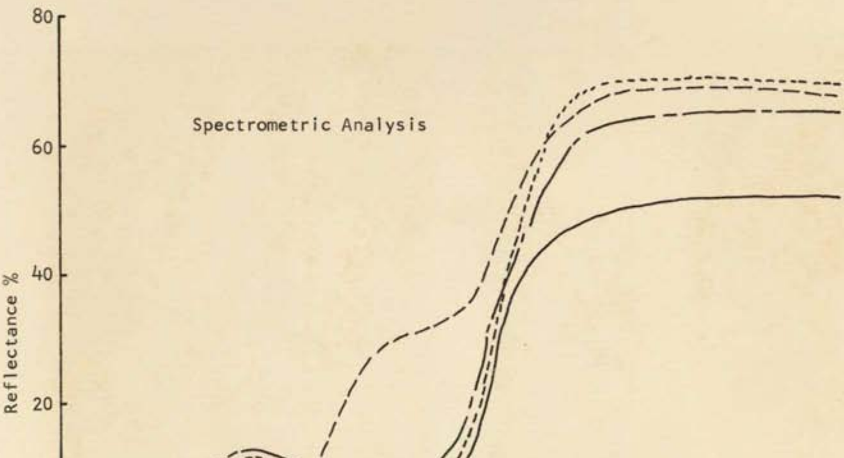


Figure 4: Spectrozonal photography offers unique advantages in mapping vegetation types. Correlations can easily be made between light reflectance curves of four Coast Range vegetation types and the tone of these types as imaged on the various film-filter combinations.

range. From these observations it would follow that on imagery employing either panchromatic film or Ektachrome color film, both of which are highly sensitive throughout the visible spectrum (400 to 700 millimicrons), Libocedrus decurrens would appear lighter on positive prints or transparencies than the other two species. Likewise, Cornus nuttallii would appear lightest on black-and-white infrared or "false color" infrared prints or transparencies and Pseudotsuga menziesii would be darker in tone than the other two species on all four film-filter combinations.

These assumptions are verified by studying the multiband photos shown in Figure 3. Upon interpreting high altitude aerial photography, similar observations were made (see Appendix I), but only to the extent that photographic tone provides a partial means of identification. Too much variability exists even in pure stands of timber to place great reliability on these characteristics.

Figure 4 is a summary graph of reflectance data and corresponding multiband aerial photos of four vegetation types occurring in the San Pablo Reservoir Test Area.

Spectral curves indicate that if a particular film-filter is to be chosen that would accentuate a tonal difference between these various species, it would have to isolate that part of the spectrum wherein variations of light reflectance for each species do not create an overlap of curves. On the left photo of Figure 4, broad vegetative groups can be distinguished on the basis of tonal differences: grass at (A), brush at (B) and timber at (C). Only on the middle photo can two brush types be accurately delineated: Rhus diversiloba (poison oak) at (D) and Baccaris pilularis (coyote brush) at (E). Recognition of the two timber types can best be done on the right photo: Umbellularia californica (California bay) at (F) and Pinus radiata (Monterey pine) at (G).

It can clearly be seen that spectrozonal photography offers unique advantages in mapping vegetation types by using tonal characteristics as the major criterion.

Color photography should provide better possibilities for determining tree species than does black-and-white photography. As stated by Heller, Doverspike, and Aldrich (1963), this is due mainly to the ability of the human eye to perceive a tremendous number of variations in color as compared to a few variations in black-and-white tones. However, the variability within a particular species still exists; therefore, color cannot provide a foolproof method of species identification (see Figure 5).

Figure 5: Libocedrus decurrens (incense cedar) may appear many shades of green on Aerial Ektachrome photography. The tree at "A" appears dark green, at "B" light green and at "C" yellow-green. Therefore, color is not a foolproof guide to species identification.

The main advantage of Aerial Ektachrome film is that timber stands are imaged in much the same color as they would appear to an observer on the ground. This enables the photo interpreter to recognize familar color trends that may apply to particular species. For example: Pinus lambertiana (sugar pine) and Abies concolor (white fir) appear white-green; Pinus ponderosa (ponderosa pine) and Libocedrus decurrens (incense cedar) appear yellow-green; Pseudotsuga menziesii (Douglas fir) and Quercus kelloggii (California black oak) appear blue-green. These are generalizations, but can provide a partial means of species identification.

Ekta Aero Infrared film is a false color film that is sensitive, not only to visible radiation, but also to near-infrared energy (700-1000 millimicrons). Similar to Aerial Ektachrome, this film can provide recognizable color trends that may help distinguish various species. For example: Pinus lambertiana (sugar pine) and Abies concolor (white fir) appink-red, while Pinus ponderosa (ponderosa pine), Libocedrus decurrens (incense cedar) and Pseudotsuga menziesii (Douglas fir) appear magenta. Ekta Aero Infrared film provides a distinct advantage over all other film-filter combinations in identifying hardwood vegetation. Many previous tests including those conducted by Jensen and Colwell (1949) and Olson and Good (1962) have pointed out the fact that hardwood foliage reflects a greater amount of light energy than coniferous foliage, especially in the near-infrared range of the spectrum. This reflected infrared energy activates the red dye on the film emulsion. Thus, vigorous hardwoods (e.g. Quercus kelloggii, Salix sp.) will invariably appear very bright red on Ekta Aero Infrared film (see Figure 6).

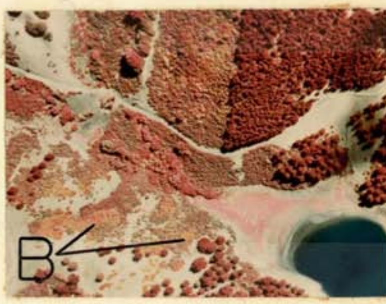
Test Site: Meadow Valley-Bucks Lake
Date: June 9, 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000

Film: Ekta Aero Infrared
Filter: Wratten 12+EF 2200
Scale: 1/28,000

Test Site: San Pablo Reservoir
Date: September 28, 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/6000



Film: Ekta Aero Infrared
Filter: Wratten 12+EF 2200
Scale 1/6000

Figure 6: The top right photo illustrates at "A" that *Salix sp.* (willow) can easily be recognized on Ekta Aero Infrared film due to the high infrared reflectance characteristics of this hardwood species. Brilliant red leaves of *Rhus diversiloba* (poison oak) are imaged in a spectacular false color, yellow, on this film type as shown at "B" in the bottom right photo.

Scale of Photography: Photographic scale and its relation to image tone must be discussed when attempting to identify tree species on aerial photographs. Of the four factors that affect image tone (spectral reflectance of the subject photographed, atmospheric conditions, film sensitivity and filter transmittance), only the atmospheric conditions change upon manipulation of scale while the other factors remain constant. Naturally, when the altitude of the camera station is increased, reflected light energy must penetrate a greater amount of atmosphere. Jensen and Colwell (1949) discuss at length the effects of atmosphere and its ability to scatter blue light. According to Rayleigh's Law, the amount of scattering of light by atmospheric haze particles varies inversely to the fourth power of the wavelength of the radiation. This means that green light (500 to 600 millimicrons) is scattered more than red light (600 to 700 millimicrons) and blue light (400 to 500 millimicrons) is scattered much more than green light. This scattering effect is commonly called haze interference.

If the flight altitude is increased, a greater amount of atmosphere must be penetrated by the reflected light energy in order to reach the film emulsion and the effects of haze interference increase. But, because it is blue light that is scattered the most, Panchromatic film with a minus-blue filter (Wratten 15) reduces the effects of haze interference. However, photography taken with Panchromatic film and a "plus-blue" filter (Wratten 47B) becomes so "foggy" at scales of 1/10,000 and smaller (corresponding in this instance to altitudes of 5,000 feet or greater) that it is useless for making tonal distinction (see Figure 7).

Film: Panchromatic
Filter: Wratten 47B
Scale: 1/10,000

Film: Panchromatic
Filter: Wratten 61
Scale: 1/10,000

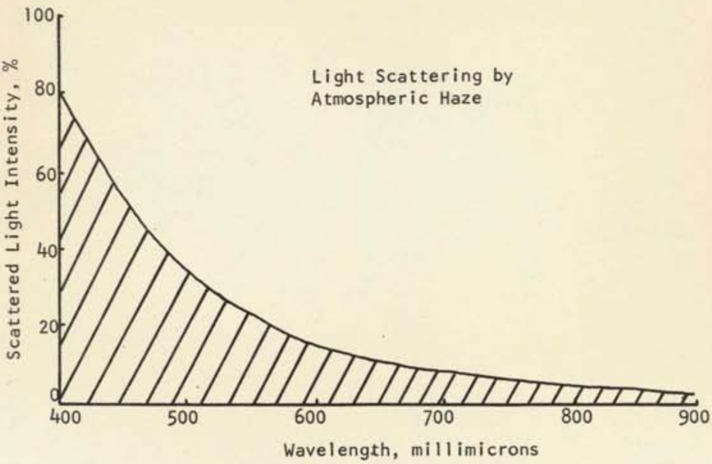


Figure 7: Haze interference can be a problem on high altitude photography causing a "foggy" image. A plus-blue filter, Wratten 47B, transmitts scattered blue light (400-500 mμ) while a green filter, Wratten 61, excludes it.

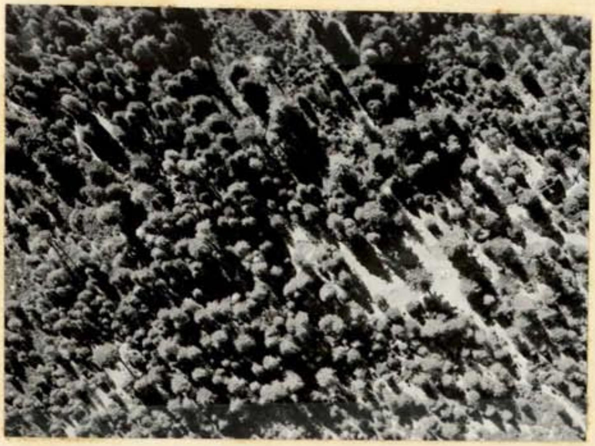
Haze interference becomes a problem on high altitude, small scale Aerial Ektachrome photography unless it is countered with the use of a haze cutting (light yellow) filter. An additional advantage to Ekta Aero Infrared film is that longer wavelengths of light (500-900 millimicrons) are recorded on the film emulsion, and a minus-blue filter is always used. Therefore, on this photography haze interference has little significance in determining tones or colors of various timber stands.

Season of Photography: Time of year has a definite influence on the appearance of image tone. Olson and Good (1962) concluded that spring or fall photography is better than midsummer photography for distinguishing trees by their tonal differences.

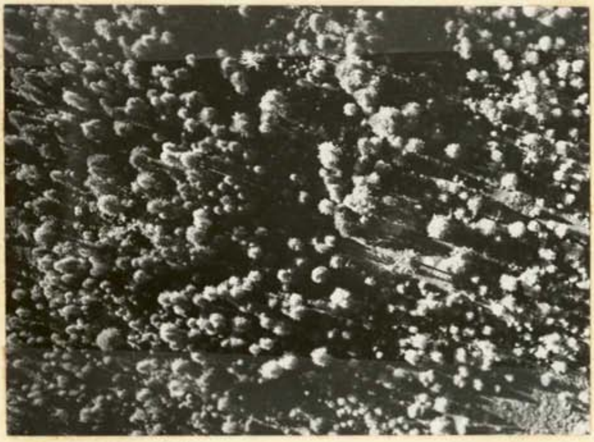
A comparison of seasonal photography of coniferous evergreen species showed little difference in results. In the fall months a slight increase in light reflectance occurs in the genus *Pinus* due to annual needle die-back (leaf drop of three and four year-old needles). Dying leaves of the genus *Abies* are generally obscured deep within the dense crown and therefore have no noticeable effect on the photographic tone of a timber stand.

In general, winter photography has less value because of the increase in shadow density occurring at that time of year. A tree's shadow can be of definite advantage in determining foliage density or crown shape, but when one wishes to discern image tone it becomes a hindrance (see Figure 8).

Situations do exist where a particular species can be identified quite easily by its tonal characteristics if it is photographed at a particular time of year. For example, *Abies concolor* (white fir) and *Abies magnifica* (red fir) have a unique method of producing cones only in the top portion of the tree crown. In certain years when this cone crop is extremely heavy, the tops of all mature white or red fir trees will be completely covered with



Film: Panchromatic
Filter: Wratten 12
Scale: 1/2,500
Season: Summer (September 9, 1964)



Film: Panchromatic
Filter: Wratten 12
Scale: 1/2,500
Season: Winter (December 13, 1964)

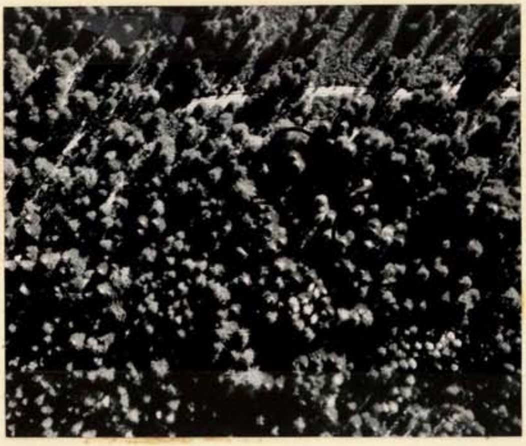
Figure 8: The low sun angle occurring in the winter months creates long shadows that are generally a hinderance in determining image tone.

cones. The fir cone is highly reflective of visible light. If a fir stand is photographed during the late fall, when the cones have matured into full size, every tree can be distinguished and correctly identified by the light-toned tree tip, contrasted with the long dark tree shadows (see Figure 9).

Increased accuracy can be obtained when distinguishing hardwoods from conifers if care is taken in selecting the optimum season for photography. For example, the leaves of Populus tremuloides (quaking aspen) turn brilliant yellow in the late fall just prior to leaf drop (see Figure 10).

Figures 10 and 11 illustrate how seasonal color changes can be evaluated by correlating sequential terrestrial photography with limited aerial photography. Sequential aerial photography taken either every few hours or once a month eventually will be highly feasible from earth orbiting reconnaissance satellites. Thus, a high degree of interpretation accuracy of deciduous hardwoods can be obtained when the following species variables can be recorded on film emulsions: actual fall coloration at specified times, and as corollaries to this, the rate of change in coloration and duration of coloration.

Photo Interpretation Equipment: All photography was viewed by the naked eye under an Abrams Model CB-1 stereoscope at two-power and four-power magnification and with a ten-power hand lens. It was found that an increase in magnification offers assistance only in the delineation of a tree's image rather than in the recognition of the image's tonal characteristics. However, determining the tree's image can be a problem, and stereoscopic observations can be of great advantage as compared to monoscopic observation. Even though best interpretation results were obtained when observing images in stereo under four-power magnification, this method



Film: Panchromatic
Filter: Wratten 25A
Scale: 1/2,500
Date: October 30, 1962

Date: July 12, 1965

Date: September 30, 1965

Figure 9: The top photo shows a mature cone crop in the top of an Abies concolor (white fir) tree. Cone development reaches a peak during the fall-seasonal state and is usually discernible on vertical aerial photography.

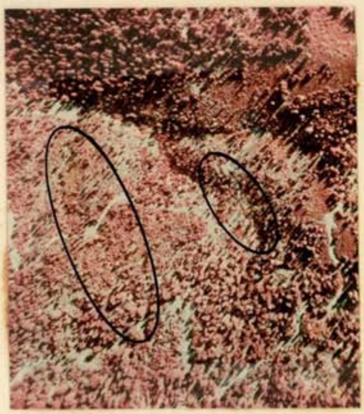
May 21 | August 2 | September 30 | October 10 | November 8

Film: Ekta Aero Infrared
Filter: Wratten 12+EF 2200
Scale: 1/25,000
Season: June 6, 1965

Film: Aerial Ektachrome
Filter: HF-2
Scale: 1/25,000
Season: September 29, 1965

Figure 10: Seasonal color changes in Populus tremuloides (quaking aspen) can be evaluated by correlating sequential terrestrial photography with limited aerial photography.

May 21 July 12 September 30 October 10 November 8



Film: Ekta Aero Infrared
Filter: Wratten 12+EF 2200
Scale: 1/10,000
Season: September 29, 1965

Film: Aerial Ektachrome
Filter: HF-2
Scale: 1/10,000
Season: September 29, 1965

Figure 11: Seasonal color changes in Cornus nuttallii (mountain dogwood) can be evaluated by correlating sequential terrestrial photography with limited aerial photography.

was not emphasized due to the anticipated lack of stereo parallax from satellite photography. It is also important to observe images with their shadows falling toward the interpreter, rather than away. A strong light source from a mobile desk lamp increased interpretation accuracy (see Figure 12).

Multi-color projection image enhancement is a new and useful technique for interpreting forest species on multiband photography. Positive transparencies made from three different multiband images are projected in common register, each through a different Kodak Wratten filter, onto a translucent screen (see Figure 13). By manipulating a series of colored filters, a finite number of false-color enhanced images can be created. Not only are several multiband images viewed simultaneously, but minute tone differences between objects of interest are enhanced. Figures 14 and 15 illustrate how false-color enhanced images facilitate the differentiation of two coniferous tree species -- Pinus radiata (Monterey pine) and Cuppressus macrocarpa (Monterey cypress). Note the similar grey tones of these two species when viewed separately on black-and-white multiband photography.

Theoretically, by projecting the correct spectral bands, an exact replica of either an Aerial Ektachrome image or an Ekta Aero Infrared image can be produced. The projected color images would have a higher degree of resolution in line pairs per millimeter than conventional color films due to: (1) the use of high resolution black-and-white film emulsions, and (2) back-scattering or "noise" occurring in tri-color film emulsions. The system can also create any false color image desired in addition to replicating conventional color films.

The usefulness of multi-color projection image enhancement, on multiband photography obtained from a reconnaissance satellite, is easily recognized considering the imagery will probably be returned to earth either in

Figure 12: Abrams stereoscope, light table and desk lamp used when interpreting imagery.

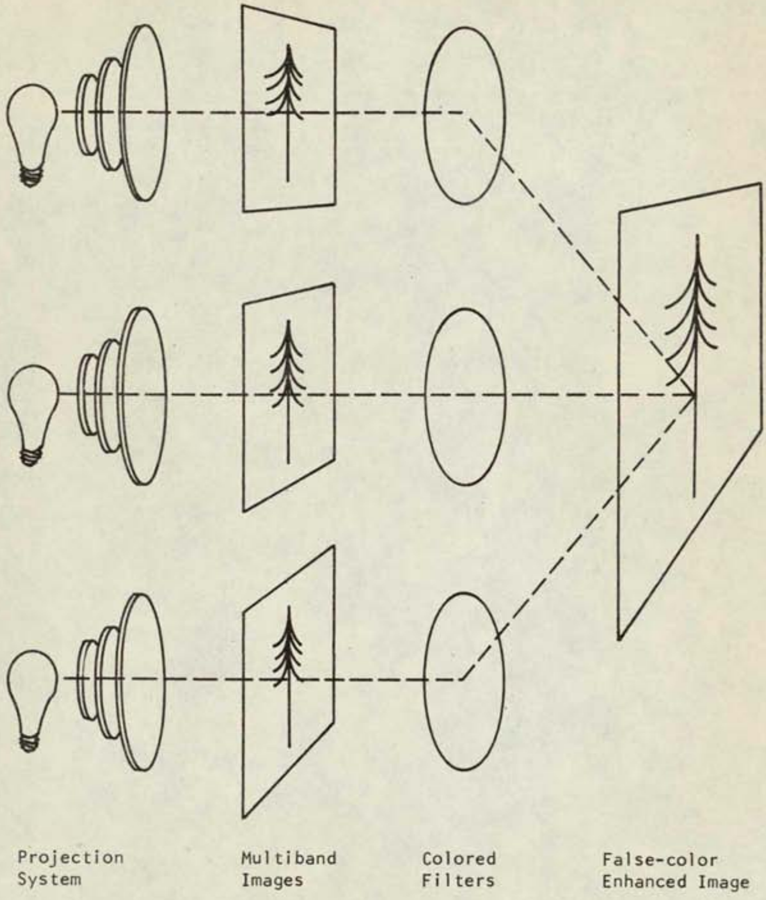
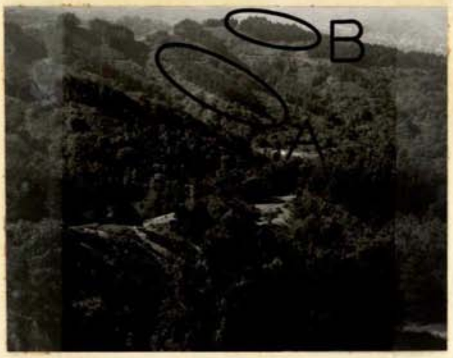
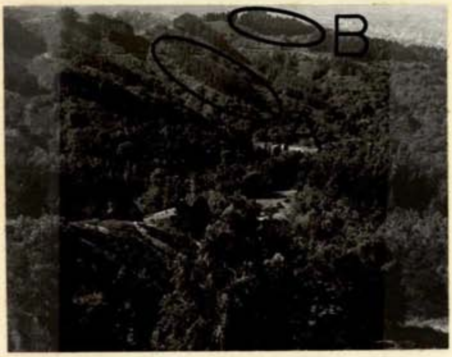


Figure 13: To produce multi-color projection image enhancement, positive transparencies made from three different multiband images are projected in common register, each through a different Kodak Wratten filter, onto a translucent screen.



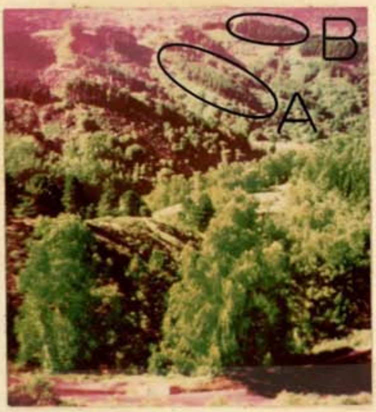
San Pablo Reservoir Test Area
Film: Panchromatic
Filter: Wratten 61



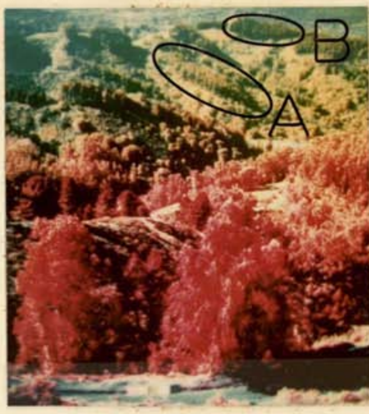
San Pablo Reservoir Test Area
Film: Panchromatic
Filter: Wratten 25A

San Pablo Reservoir Test Area
Film: Infrared
Filter: Wratten 89B

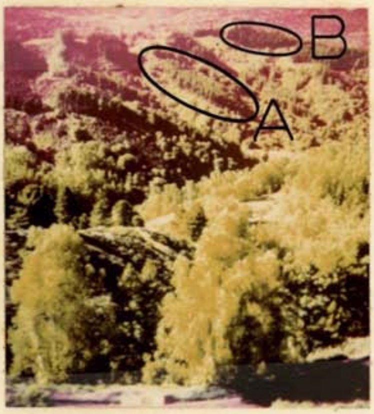
Figure 14: Positive transparencies of these multiband photos were used to create the false-color enhanced images seen in Figure 15. Note the similar tone signatures of Pinus radiata (Monterey pine) at A and Cupressus macrocarpa (Monterey cypress) at B.



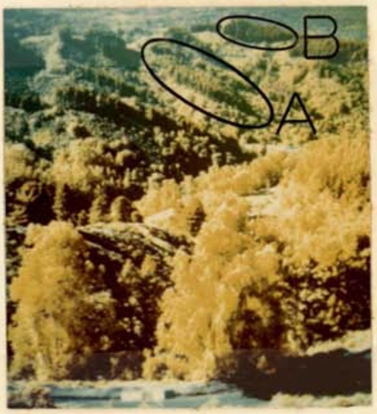
Pan 61 with a Wratten 50 Filter
Pan 25A with a Wratten 70 Filter
IR 89B with a Wratten 74 Filter



Pan 61 with a Wratten 74 Filter
Pan 25A with a Wratten 50 Filter
IR 89B with a Wratten 70 Filter



Pan 61 with a Wratten 70 Filter
Pan 25A with a Wratten 50 Filter
IR 89B with a Wratten 90 Filter



Pan 61 with a Wratten 74 Filter
Pan 25A with a Wratten 50 Filter
IR 89B with a Wratten 90 Filter

Figure 15: Multi-color projection image enhancement is a new and useful technique for interpreting multiband photography. Not only are several images viewed simultaneously, but minute tone differences between objects of interest are enhanced (i.e. *Pinus radiata* at A and *Cupressus macrocarpa* at B).

recoverable cassettes containing high resolution black and white emulsions or by line scan television transmission.

Exposure and Processing: The adverse effects that improper exposure and processing would have on the ability to recognize tonal differences occurring between stands of different tree species are obvious. Accurate light meter readings and corrections to exposure time according to filter factors should be made because variations from optimum exposure are likely to result in reduced accuracy when interpreting image tone.

Photographic Detail

Tree morphology can be described as the branch of biology concerning tree form and structure, without regard to functions. Historically, the classification of different animal and plant types into precise orders, families, genera and species has been based on phenotypic rather than genotypic differences within these types. These physical differences are usually easily discernible upon visual observation. Likewise, the classification of different tree types into family, genus, and species usually can be done quite easily by observing the morphological characteristics of the particular trees. It would follow that tree species identification on vertical aerial photographs often would merely involve the recognition of these same morphological differences. However, a tree's structure observed from a position high above or from space provides a limited number of visible morphological features compared to observations made from a position on the ground. Limb or branch orientation, trunk form, bark configuration, and cone development are a few of the important features of a tree that ordinarily are not imaged on conventional vertical aerial photographs, even when studied stereoscopically. Tree height, crown margin and crown apex are the primary morphological characteristics discernible about a tree from the vertical view. Therefore, the crown margin and apex of each species must be thorougly understood by the photo interpreter before accurate interpretation can be made.

Recognition of timber stand form and structure from earth orbit is sometimes difficult to visualize. The theoretical resolving power obtainable from a reconnaissance satellite at an altitude of 142 miles is presented in Table I. A conventional twelve inch focal length mapping camera stationed in space, capable of resolving 40 line pairs per millimeter, could image objects no smaller than 60 feet in diameter. However, the U.S. Air Force has developed elaborate camera systems with focal lengths up to 240 inches. Based on information presented by Amrom Katz (1960), film capable of resolving 1,000 line pairs per millimeter is possible with present state of the art; film resolving 100 line pairs per millimeter is commonplace. Theoretically, (and assuming no diffraction-limiting conditions) the most efficient system mounted in orbiting satellites could resolve ground objects as small as 0.12 feet in diameter! Even when this optimistic resolution figure is appropriately corrected, we find that photographic detail is, potentially, an important image characteristic when evaluating the forest resource from space.

Table I: THEORETICAL RESOLVING POWER OBTAINABLE FROM A RECONNAISSANCE SATELLITE AT AN ALTITUDE OF 142 MILES

Focal Length	Scale of Photography	Ground Resolution, Assuming Negatives That Will Resolve (40 lines/mm)	(100 lines/mm)	(1000 lines/mm)
12 inches	1/750,000	60 feet	24 feet	2.4 feet
36 inches	1/250,000	20 feet	8 feet	0.8 feet
120 inches	1/75,000	6 feet	2.4 feet	0.24 feet
240 inches	1/57,500	3 feet	1.2 feet	0.12 feet

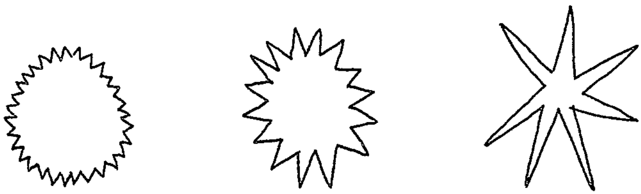
CROWN MARGIN

ENTIRE - margin even, not toothed

CRENATE - margin notched with rounded teeth

SINUATE - margin wavy

LOBED - margin deeply rounded



DENTICULATE - margin minutely sawtoothed

DENTATE - margin deeply sawtoothed

PARTED - margin deeply recessed, star-shaped

CROWN APEX

TRUNCATE - apex cut off squarely

ROUNDED - apex broadly rounded

OBTUSE - apex bluntly rounded

OVATE - apex bluntly pointed

ACUTE - apex termination in an angle, less than 90%

ACUMINATE - apex gradually diminishing

Figure 16: Schematic drawings of tree morphology as seen on aerial photography.

<u>Film-Filter</u>: Recognition of tree morphology can offer a reliable guide to tree species identification, and certain film-filter combinations produce slightly better results than others.

Jensen and Colwell (1949) presented a theoretical analysis of the relative suitability of various bands of the spectrum for obtaining maximum clarity of detail in aerial photography of forested areas. Panchromatic film with a green filter will theoretically provide a maximum photo detail because, in the green part of the spectrum, foliage reflectance is higher than elsewhere in the visible spectrum and film sensitivity is high. This film-filter combination should be better than Panchromatic "plus-blue" because of the previously-mentioned haze interference factor encountered in the blue end of the spectrum. According to Ryker (1934), reflected red and orange light produces annoying glare; therefore, Panchromatic "plus-green" which partially excludes light in this part of the spectrum, would be better than Panchromatic "plus-blue" (see Figure 17).

Jensen and Colwell found no appreciable difference in photo detail between Panchromatic minus-blue and Panchromatic green at scales of 1/15,000 or smaller. However, at such scales tree morphology cannot be resolved (assuming low resolution conventional film types) and emphasis is placed on image tone rather than photo detail. Ryker found that at larger scales, where photo detail becomes the determining factor in recognizing species, Panchromatic green is superior to all other film-filter combinations.

The present study indicates that, at the scales and associated flight altitudes here considered, Panchromatic "plus-blue" is definitely an inferior film-filter combination for displaying photographic detail. Haze in-

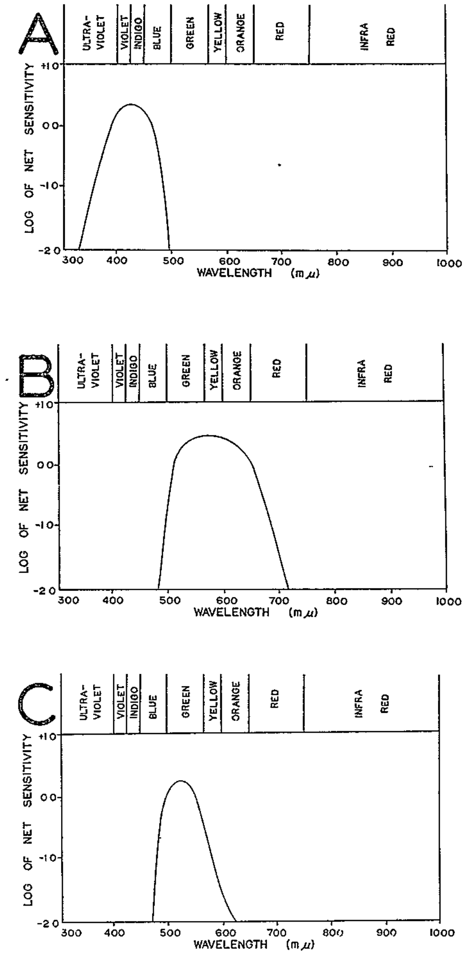


Figure 17: Net sensitivity curves combining effects of film sensitivity and filter transmittance for panchromatic film and a plus-blue filter (A), minus-blue filter (B) and green filter (C).

terference, combined with minimum foliage reflectance, creates a poor image. However, even at the larger scales (1/5,000 and 1/2,500), little difference was found between Panchromatic minus-blue and Panchromatic green.

Either of the color films (Aerial Ektachrome or Ekta Aero Infrared) is superior to Panchromatic photography when interpreting tree morphological characteristics on aerial photos. The color films are a positive transparency type. This means the original sheet of film emulsion is observed over a light table as a positive transparency rather than a resultant photographic print. Both the color and Panchromatic films used in this study are of the fine-grained, medium-high resolution type. However, the process of printing an image from a panchromatic negative onto photographic paper reduces the resolving power of the resulting image. Therefore, the elimination of printing from color transparency film allows it to be more useful for recognizing photographic detail than panchromatic film.

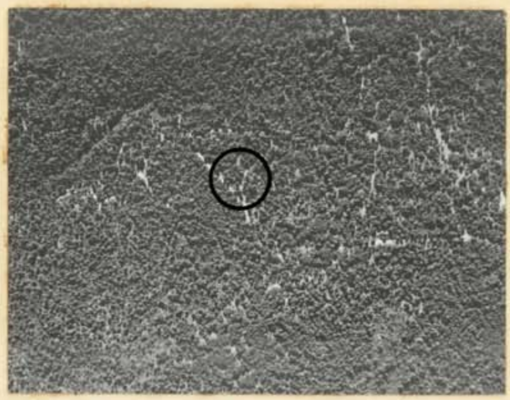
Scale of Photography: Undoubtedly photographic scale has a tremendous influence on the discernibility of tree morphology on aerial photographs. The unaided human eye is capable of resolving approximately 7 to 8 lines per millimeter. When the image of a timber stand becomes extremely small on a photograph due to a reduction in scale, tree morphology can no longer be resolved by the retina of the eye. The ability of the human eye to resolve minute detail, the resolving power of the film emulsion, plus the relative degree of size of detail corresponding to each species type will determine the optimum scale for identifying that species. Generally, film resolution is the limiting factor when interpreting high altitude small scale conventional photography under magnification.

The structural characteristics of one species are often more apparent than those of another species. For example, the grotesque "star shaped" branching of a mature Pinus lambertiana (sugar pine) can sometimes be discerned on aerial Ektachrome at a scale of 1/10,000. Much greater reliance can be placed on this means of identifying sugar pine on 1/5,000 photography. In fact, all species of the mixed conifer forest type but one, Libocedrus decurrens (incense cedar), can generally be recognized on 1/5,000 aerial Ektachrome or Ekta Aero Infrared film by using morphological characteristics as a means of identification.

Libocedrus decurrens (California incense cedar) is a difficult species to identify from a vertical view because of its similarity to Pinus ponderosa (ponderosa pine). A ground observer generally distinguishes this species from pine by its bark characteristics and leaf pattern. However, neither of these factors is readily visible on aerial photos. Even at scales larger than 1/2,500 identification would be difficult.

At the largest scale studied, 1/2,500, panchromatic photography offers good photographic detail of Pinus lambertiana (sugar pine) and Abies concolor (white fir), thus allowing accurate identification of these species (see Figure 18). In addition to the wide spreading crowns of Quercus kelloggii (California black oak) the only species that can be even partially identified in the mixed conifer type on black-and-white photos at a scale of 1/5,000 is the "star-shaped" Pinus lambertiana (sugar pine).

Season of Photography: In order to obtain maximum advantage of tree morphology as a guide to species identification, stand structure must not be obscured by shadow. For this reason, spring, summer and fall photography will produce better interpretation results than winter photography. Occasionally, in open stands, shadow detail is examined as an indication of crown structure, at which time long shadows are more informative than short inconspicuous shadows. However, long shadows are usually more of a



Film: Panchromatic
Filter: Wratten 12
Scale: 1/10,000

Film: Panchromatic
Filter: Wratten 12
Scale: 1/2,500

Figure 18: Pinus lambertiana (sugar pine), circled, and Abies concolor (white fir), squared, can easily be identified on this panchromatic photography, scale 1/2,500, using tree morphology as a guide. Little information is obtainable from small scale conventional photography; however, long-focal length, high-resolution systems planned for satellite reconnaissance could theoretically resolve detail small enough to reveal many morphologic features of tree crowns.

hindrance than an aid when determining tree morphology.

If deciduous hardwood stands are to be separated from evergreen conifer stands and only panchromatic photography is available, late season imagery may prove advantageous. For example, Quercus kelloggii (Californin black oak) and Quercus douglasii (blue oak) have a peculiar "spiny" shape when observed from vertically above on winter photos (see Figure 19).

Photo Interpretation Equipment: The Abrams Model CB-1 stereoscope proved satisfactory for studying tree stand morphology. Both panchromatic and color photography could be examined under four-power magnification (and in stereo when desired) with this device. It was also found that when the species composition of a timber stand is in question, additional information concerning tree morphology can be obtained by observing the image under a ten-power land lens.

When selecting conventional film types that simulate imagery from reconnaissance satellites, a fine-grained, medium-contrast and high-resolution film should be used in order to assure maximum photo detail.

Exposure and Processing: In addition to proper exposure, as mentioned in reference to image tone, care must be taken in printing to provide maximum image detail. An automatic contrast-control printer (e.g. the "Log-Etronic" model) provides greater uniformity of density in all parts of the print while preserving adequate contrast in minute detail.

Large scale photography is often plagued by image blue which is caused by the rapid movement of the camera station (airplane). This blurring effect destroys minute image detail and must be compensated for within the aerial camera system. A high speed aerial film, by permitting the use of a fast camera shutter speed, virtually eliminates image motion at scales of 1/2,500 or smaller. Image motion rarely presents a problem

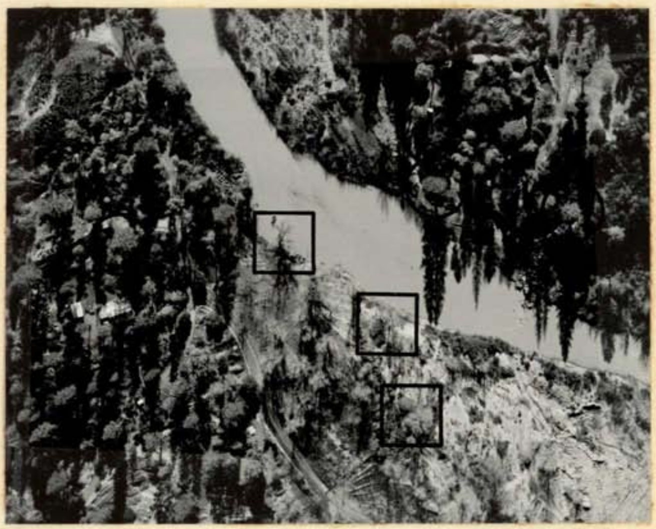


Figure 19: Winter aerial photography allows easy separation of evergreen conifers (circled) from leafless hardwoods (squared).

with high altitude small scale aerial photography. On space photography, the problem is potentially more serious, however. If the space which is travelling in earth orbit at the conventional speed of 18,000 miles per hour (approximately 25,000 feet per second) there obviously is a potential image blur of 250 feet, in the direction of flight, when the exposure time (shutter speed) is 1/100 second. This difficulty can be largely remedied by using the principle of "forward motion compensation" by which the film is travelling inside the camera (even while an exposure is being made) at the same rate as images are moving across the camera's focal plane. This process serves to "freeze" the image of a given feature to a given portion of film throughout the period of exposure, thereby minimizing image blur.

FEASIBILITY RATINGS FOR THE PHOTO INTERPRETATION OF REPRESENTATIVE FOREST SPECIES IN CALIFORNIA

On the succeeding two pages are tables indicating the feasibility of detecting and identifying representative forest species found to occur in three study areas in California. Photography was flown with four different film-filter combinations (Aerial Ektachrome, Ekta Aero Infrared, panchromatic minus-blue and black-and-white infrared) at each of three photographic scales and at various seasonal states. The symbols appearing in the various squares of these tables have the meanings indicated in the legend. The ratings represent the consensus of several photo interpreters who were actively engaged in this research, each of whom independently assigned feasibility ratings for each square of the tables. The ratings are based on a maximum of four-power magnification.

In arriving at these ratings, each photo interpreter had access to many photographic examples of the types appearing in the photo interpretation key (see Appendix I). For each example, accurate ground truth, (including stereo ground shots) had been obtained either at the instant of aerial photography, or very shortly thereafter. It was often necessary to extrapolate from aerial photographic examples that had been flown to specifications that were similar to, but not identical with those called for in some particular square of the tables. Nevertheless, the range for photographic scales that would simulate reconnaissance satellite imagery (the 1/30,000 to 1/35,000 range) was well covered by high altitude, small scale aerial photography.

FEASIBILITY OF IDENTIFYING REPRESENTATIVE FOREST SPECIES IN CALIFORNIA ON HIGH-ALTITUDE, SMALL-SCALE AERIAL PHOTOGRAPHY UTILIZING VARIOUS PHOTOGRAPHIC SPECIFICATIONS

Test Area	Species	Scale: 1/2,500				Scale: 1/10,000				Scale: 1/30,000			
		Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR
San Pablo Reservoir	<u>Pinus radiata</u>	++	++	+	++	++	++	-	+	++	++	-	+
	<u>Eucalyptus globulus</u>	++	++	+	+	+	++	-	+	-	+	--	-
	<u>Quercus agrifolia</u>	++	++	+	+	+	+	-	-	-	+	--	-
	<u>Umbellularia californica</u>	++	++	+	+	+	+	-	-	-	+	--	-
	<u>Salix sp.</u>	++	++	+	+	+	+	-	-	-	+	--	-
	<u>Aesculus californica</u>	++	++	+	+	-	+	--	-	-	+	--	--
Meadow Valley-Bucks Lake	<u>Pinus ponderosa</u>	++	++	+	+	+	++	-	-	+	+	-	-
	<u>Pinus contorta</u>	++	++	+	+	+	++	-	-	+	++	-	-
	<u>Pinus lambertiana</u>	++	++	++	++	++	++	+	+	+	+	-	-

Legend: ++ consistently identifiable as to species
+ occasionally identifiable as to species
- rarely identifiable as to species
-- not identifiable as to species
0 no example

Test Area	Species	Scale: 1/2,500				Scale: 1/10,000				Scale: 1/30,000			
		Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR
Meadow Valley-Bucks Lake (continued)	<u>Abies magnifica</u>	++	++	+	+	+	++	-	-	+	+	-	-
	<u>Abies concolor</u>	++	++	+	+	+	++	-	-	+	+	-	-
	<u>Pseudotsuga menziesii</u>	++	++	+	+	+	+	-	-	+	+	-	-
	<u>Libocedrus decurrens</u>	+	+	-	-	-	+	-	-	-	+	--	--
	<u>Quercus kelloggii</u>	++	++	+	++	+	++	-	+	+	++	-	+
	<u>Acer macrophyllum</u>	++	++	+	+	++	++	+	-	+	+	-	--
	<u>Populus trichocarpa</u>	++	++	+	+	+	++	-	+	+	++	--	-
	<u>Alnus tenuifolia</u>	++	++	+	+	+	++	-	-	+	+	-	-
	<u>Populus tremuloides</u>	++	++	+	+	+	++	-	-	+	++	--	-
	<u>Salix sp.</u>	++	++	+	++	+	++	-	+	-	+	--	-
	<u>Cornus nuttallii</u>	++	++	-	-	++	++	--	--	+	+	--	--

Legend: ++ consistently identifiable as to species
+ occasionally identifiable as to species
- rarely identifiable as to species
-- not identifiable as to species
0 no example

Test Area	Species	Scale: 1/2,500				Scale: 1/10,000				Scale: 1/30,000			
		Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR	Ekta	Ekta-IR	Pan	IR
Geysers	<u>Cuppressus sargentii</u>	++	++	+	+	+	++	-	-	0	0	0	0
	<u>Pinus sabiniana</u>	++	++	+	-	++	++	-	-	0	0	0	0
	<u>Pseudotsuga menziesii</u>	++	++	+	+	++	++	+	+	0	0	0	0
	<u>Pinus attenuata</u>	++	++	-	++	+	+	--	+	0	0	0	0
	<u>Quercus lobata</u>	++	++	-	+	++	++	-	-	0	0	0	0
	<u>Acer macrophyllum</u>	++	++	-	+	+	++	-	-	0	0	0	0

Legend: ++ consistently identifiable as to species
+ occasionally identifiable as to species
- rarely identifiable as to species
-- not identifiable as to species
0 no example

SUMMARY AND CONCLUSIONS

This study has sought to analyze the effects of photographic specifications (film-filter combination, resolution, scale, season, exposure and processing) and of photo interpretation equipment on the discernibility of image tone and detail for the identification of California tree species. Situations are cited where the manipulation of a particular factor proved to be critical for the recognition of certain species. The following general conclusions concerning optimum photographic specifications for all species studied can be made:

1. Film-filter combination

a. All species studied, excluding *Libocedrus decurrens* (incense cedar) can be accurately identified on large scale (= 1/5000) Aerial Ektachrome transparencies. Accuracy of interpretation will increase slightly at larger scales.

b. Large scale Ekta Aero Infrared transparencies give less accurate results than Aerial Ektachrome photography. However, all species studied except incense cedar can generally be identified.

c. Interpretation of high-altitude,small-scale photography (on which only timber stands rather than individual trees can be resolved) indicates Ekta Aero Infrared as the best film-filter combination for recognizing most species.

d. Panchromatic photography at scales smaller than 1/2,500 is relatively useless for species identification except when classifying vegetation types into broad groups (e.g. deciduous hardwoods, evergreen conifers, riparian hardwoods, etc.).

e. Black-and-white infrared photography at scales smaller than 1/2,500 is of very limited value for species identification. However, this film type is superior to panchromatic photography when classifying vegetation types into broad groups.

f. Differences existing between panchromatic green (Wratten 61 filter) and panchromatic minus-blue (Wratten 12 filter) photography proved so slight that one film-filter combination could not be preferred over another when identifying tree species.

g. Panchromatic "plus-blue" (Wratten 47B filter) photography was the poorest of all film-filter combinations studied.

2. Photographic scale

a. Conventional high-altitude aerial photography, scale 1/30,000 to 1/40,000, can be used to simulate imagery obtainable from earth orbiting reconnaissance satellites.

b. Haze interference becomes a problem on high altitude panchromatic and Aerial Ektachrome photography unless it is countered with the use of a minus-blue or stronger filter to screen out short wavelengths.

c. The ability of the human eye to resolve minute detail, the resolving power of the camera lens and film emulsion, plus the size of detail required to identify each species will determine the usefulness of aerial photography flown at any given scale for identifying that species. Generally, film resolution is the limiting factor when interpreting high altitude small scale conventional photography.

3. Season of photography

a. An Abrams Model CB-1 stereoscope, ten power hand lens, light table and desk lamp proved satisfactory as equipment aids for interpreting imagery.

b. Multicolor projection image enhancement is a new and useful technique for interpreting forest species on multiband photography. Several multiband images can be viewed simultaneously by this means and minute tone differences between objects of interest can be color-enhanced.

c. When selecting conventional film types that simulate imagery from reconnaissance satellites, a fine-grained, medium-contrast and high-resolution film should be used in order to obtain maximum photo detail.

5. Exposure and processing

a. Accurate light meter readings and corrections to exposure time according to filter factors should be made because variations from optimum exposure are likely to result in reduced accuracy when interpreting image tone.

b. An automatic contrast-control printer, (e.g. the "Log-Etronic" model), provides greater uniformity of density in all parts of the print while preserving adequate contrast in minute detail.

RECOMMENDATIONS

The study of the feasibility of identifying forest species and delineating major timber types in California by means of high altitude small scale aerial photography should be continued because:

(1) The studies conducted in the San Pablo Reservoir and Bucks Lake - Meadow Valley areas are very encouraging. These studies indicate that homogeneous stands of timber (e.g., Eucalyptus globulus, blue gum eucalyptus or Pinus radiata, Monterey pine) can be distinguished from adjacent homogeneous or heterogeneous stands on high altitude aerial photography. However, estimation of species composition within heterogeneous, mixed stands is much more difficult. Emphasis must be on an analysis of varying phenological characteristics inherent in plants and discernible on imagery flown to the proper specifications. A number of photo missions would be required to give adequate aerial coverage of seasonal changes occurring during the critical growing season in the spring and also during the leaf drop period in the fall.

(2) Multi-color projection image enhancement of multiband imagery taken from a stationary terrestrial camera station has proved to be a useful technique for interpreting forest species. High-altitude, small-scale black-and-white multiband imagery should be flown of additional test areas in California and positive transparencies made from the different multiband images should be projected in common register, each through a different Kodak Wratten filter, onto a translucent screen. By this system not only are several images viewed simultaneously, but minute tone differences between objects of interest are enhanced.

(3) The photo interpretation keys of representative timber species occurring in California need to be improved. Additional photography flown to optimum specifications (film, filter, scale and season) should be taken

of the prescribed test areas and of additional study areas. The interpretation results of this photography should be incorporated into the existing keys or used to develop new keys.

(4) Qualitative and quantitative analyses should be made on the usefulness of the photo interpretation keys to timber types and species. Additional on-the-ground surveys of type boundaries, stand composition and stand density should be made by field crews in several different regions of the state. Timber type maps constructed from high altitude, small scale aerial photography, simulating reconnaissance satellite imagery, should be compared with the 100% ground truth survey maps.

(5) Highly encouraging preliminary evaluations of multiband (ultraviolet, visible, near infrared and thermal infrared) imagery of forest types in Yosemite Valley have been made. This type of multiband imagery should be acquired of the prescribed test areas and its usefulness as an aid for forest inventory should be evaluated.

BIBLIOGRAPHY

Cahusac, A. B., Forest Mapping from Aerial Photography - Uganda. Paper presented to the 7th British Comm. Forestry Conference, 1957, 1-5, 1957.

Chase, C. S., and Korotov, J., Key to Forest Types in Marinette County, Wisconsin, on Infrared Minus-blue Filter at 1/12,000, Autumn Photography. (Processed. Copy in the Langlois Library, Catholic University, Washington, D.C.), 1947.

Colwell, R. N., Report of Commission VII to the International Society of Photogrammetry. PHOTOGRAMMETRIC ENGINEERING, 18(3):375-400, 1952.

Francis, E. C., and Wood, G. H., Classification of Vegetation in Northern Borneo from Aerial Photos. Proceedings 4th World Forestry Conference. Dehra Dun, 1956 (1958), 623-9, 1954.

Heller, R. C., Doverspike, G. E., and Aldrich, R. C., Identification of Tree Species on Large-Scale Panchromatic and Color Aerial Photographs. PHOTOGRAMMETRIC ENGINEERING, 29(3)·477, 1963.

Hindley, Earle and Smith, H. G., Spectrophotometric Analysis of Foliage of Some British Columbia Conifers. PHOTOGRAMMETRIC ENGINEERING, 23(5):894-895, 1957.

Jensen, H. A. and Colwell, R. N., Panchromatic Versus Infrared Minus-blue Aerial Photography for Forestry Purposes in California. PHOTOGRAMMETRIC ENGINEERING, 15·201-223, 1949.

Katz, Amrom H , Observation Satellites: Problems and Prospects. ASTRONAUTICS (American Rocket Society, Inc., New York). June 1960.

Mc Minn, H. E., and Maino, E., PACIFIC COAST TREES. University of California Press, Berkeley and Los Angeles, 406 pp., 1959.

Miller, R G., The Interpretation of Tropical Vegetation and Crops on Aerial Photos. PHOTOGRAMETRIA, 16(3):232-240, 1960.

Olson, C. E., and Good, R. E., Seasonal Change in Light Reflectance from Forest Vegetation. PHOTOGRAMMETRIC ENGINEERING, 28(1):107, 1962.

APPENDIX I - PHOTO INTERPRETATION KEYS

Raup, H., and Denny, C. S., Photointerpretation of the Terrain Along the Southern Part of the Alaska Highway. Geological Survey Bulletin, 963-D. U.S. Government Printing Office, Washington, D.C., 1950.

Rhker, H. C., Aerial Photography: A Method of Determining Timber Species. TIMBERMAN, 34(5):11-17, 1933.

Sayn-Wittgenstein, L., Recognition of Tree Species on Air Photo by Crown Characteristics. PHOTOGRAMMETRIC ENGINEERING, 27(5):792-809, 1961.

Seeley, H. E., Air Photography and Its Application to Forestry. Forestry Air Survey Publication; No. 6. Canada Department of Mines and Resources, Ottawa, Canada, 1949.

Sonley, G. R., Interim Report on Experimental Air Photography for Forest-Cover Classifications. FOREST CHRONICLE, 22(2):157-158, 1946.

Spurr, S H., and Brown, C. T, Specifications for Photographs Used in Forest Management. PHOTOGRAMMETRIC ENGINEERING, 12(2):131-141, 1946

Steigerwaldt, E. F., Outline of the State of Wisconsin Forest Inventory. Unpublished Manuscript. Forest Protection Headquarters, Tomahawk, Wisconsin, 1948.

Stone, K. H., Aerial Photographic Interpretation of Natural Vegetation in the Anchorage, Alaska Area. SURVEY AND MAPPING, 10(3):261, 1950.

Zsilinszky, V. G., The Practice of Photo Interpretation for a Forest Inventory. PHOTOGRAMMETRIA, Vol. XIX:192-208, 1962-1964.

PHOTO INTERPRETATION KEYS

A photo interpretation key is "reference material designed to facilitate rapid and accurate identification and determination of the significance of objects or conditions from the analysis of their photo images" (Colwell, 1952). Without knowledge or familiarity of a given area supplemented with accurate "ground truth", a photo interpreter can only draw on past experience when identifying objects on aerial photos. However, if some type of reference material or guide is available, depicting a means of identifying the same area or similar area, accurate interpretation can be made regardless of photo interpretation experience or familiarity with the area.

The most useful key for the recognition of tree types consists of three parts: (1) a word description of each species as imaged on aerial photos that utilize pre-determined optimum photographic specifications, (2) representative aerial photography and schematic drawings that illustrate each species, and (3) a word description of tree height, tone, and morphological differences arranged in a dichotomous fashion so that each species can be easily eliminated upon recognition of its photographic features.

Actually this system consists of two types of keys. The dichotomous system is referred to as "elimination key" while the work description and photo illustration of each species is called a "selective key". Whichever key is used for the identification of a particular species, the other form of key should be used as a check which will ensure more accurate species identification.

Pinus radiata

(Monterey Pine)

San Pablo Reservoir Test Area

Distribution: Native in San Mateo, Monterey, and northern San Luis Obispo Counties where the species is found on gentle to moderate slopes, from sea level to a maximum near 1000 feet, and from the coast line to about six miles inland. Planted in parks and gardens and, especially in coastal California, for reforestation.

Soils: Grows on a variety of soils developed from different parent materials. The soils are characteristically coarse-textured sandy loams, strongly acid, and at least moderately permeable. On the best sites, the soil is well-drained, moderately deep sandy loam. The characteristic patterns of fog movement inland seems to explain the distribution of the Monterey pine forest where other factors are not limiting.

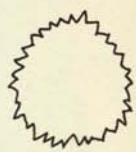
Assoc. Species: Coast live oak, valley oak, California bay, blue gum eucalyptus, willow, buckeye, bigleaf maple.

Crown apex:

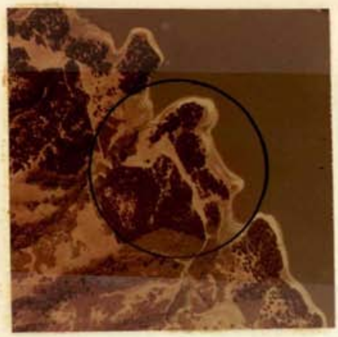
obtuse

Crown margin:

denticulate



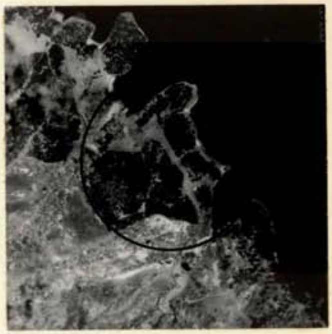
Pinus radiata



Film: Aerial Ektachrome
Filter: None
Scale: 1/20,000
Date: September 1965

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/20,000
Date: June 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: August 1958



Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 40 to 100 foot evergreen tree with a straight trunk. Stout spreading branches form a compact, often irregular, round to obtuse crown apex. The finely sawtoothed crown margin becomes obscured at scales of 1/5000 or smaller. The tree appears dark green on aerial ektachrome and dark red on ekta aero infrared film. On panchromatic photography, the tree is generally darker in tone than ponderosa pine, digger pine and white fir, but appears very similar to Douglas fir. On infrared photography, it is easily identified as a coniferous species but specific species identification is difficult.

Eucalyptus globulus

(Blue gum Eucalyptus)

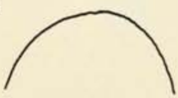
San Pablo Reservoir Test Area

Distribution: Native to Australia. Extensive plantations have been established in California. Those in the East Bay were planted around 1900 as well as during the 1930's. Some have occasionally established themselves outside of cultivation.

Soils: Generally prefers deep, moist fertile soils such as well-drained gully-bottoms and undulating coastal area. Optimum growth is evident on heavier soils or good moist loams. Even on poor sites, however, the species will do well because of its very rapid growth rate. In Australia it grows in a cool, moist climate near the coast (mostly in Tasmania), from sea level to about 1000 feet.

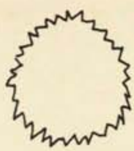
Assoc. Species: Coast live oak, valley oak, California bay, Monterey pine, willow, buckeye, bigleaf maple.

Crown apex:



rounded

Crown margin:



denticulate

Eucalyptus globulus

Film: Aerial Ektachrome
Filter: None
Scale: 1/6,000
Date: September 1965

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/6,000
Date: September 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: August 1958

Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 70 to 140 foot evergreen hardwood tree with stout spreading branches forming a round-topped crown. Drooping foliage on spreading branchlets gives the crown margin a minutely sawtoothed appearance which is sometimes visible on 1/20,000 photography. The tree appears bluish-green on aerial ektachrome and brownish-red on ekta aero infrared transparencies. On color infrared photography most deciduous hardwoods appear brighter red and most conifers appear darker red than eucalyptus. On panchromatic and black and white infrared photos eucalyptus is dark grey in tone and is easily confused with most coniferous species.

Quercus agrifolia

(Coast Live Oak)

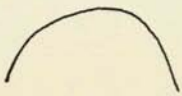
San Pablo Reservoir Test Area

Distribution: Native on the lower mountain slopes, rocky hills, and on valley flats of the Coast Ranges from Sonoma and Napa Counties southward to the mountains of southern California. Usually found at elevations below 3000 feet and requires moderate soil moisture.

Soils: Can tolerate a wide range of soil conditions throughout its range. Will grow on shallow dry soils of exposed slopes as well as on better soils of protected valleys. Exhibits best growth on deep, well-drained soils with adequate soil moisture.

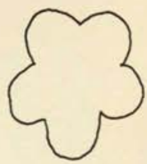
Assoc. species: Valley oak, California bay, blue gum eucalyptus, Monterey pine, willow, bigleaf maple, buckeye.

Crown apex:



rounded

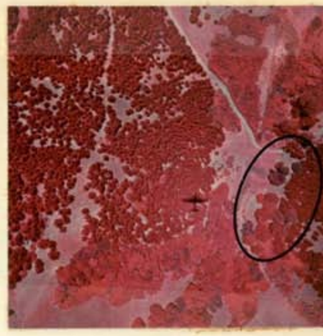
Crown margin:



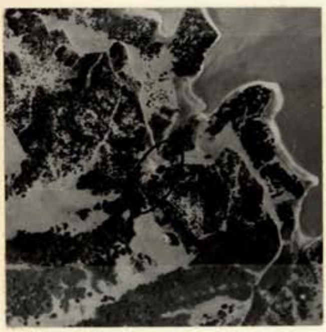
lobed

Quercus agrifolia

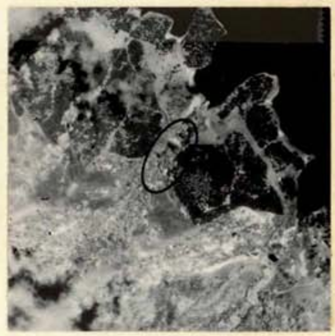
Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: May 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: May 1966



Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: May 1959



Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) An evergreen tree, 30 to 75 feet high, with spreading branches from a trunk dividing a few feet above the ground forming a broad rounded crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. This species is very susceptible to attacks by California oakworm larvae (*Phryganidia californica*) which occurs in epidemic magnitudes once every five to seven years. When under attack, the tree appears very grey green on aerial ektachrome and grey on ekta aero infrared transparencies. On panchromatic and black and white infrared photos live oak is similar in appearance to most other evergreen hardwoods.

Umbellularia californica

(California Bay)

San Pablo Reservoir Test Area

Distribution: Native to canyon walls, mountain slopes, and stream flats of the Coast Ranges and the Sierra Nevada from southwest Oregon to the mountains of southern California. Usually grows from sea level to 3000 feet elevation.

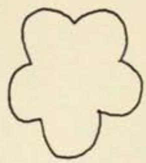
Soils: Most abundant and of largest size on alluvial soils of river flats of northwestern California and adjacent Oregon. Most common on deeper soils of protected mountain slopes with moderate soil moisture.

Assoc. Species: Coast live oak, valley oak, blue gum eucalyptus, Monterey pine, willow, bigleaf maple, buckeye.

Crown apex:

rounded

Crown margin:



lobed

Umbellularia californica

Film: Aerial Ektachrome
Filter: None
Scale: 1/20,000
Date: September 1965

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/20,000
Date: June 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: May 1959

Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) An evergreen tree, 20 to 75 feet high, or shrub-like in open dry habitats, with ascending branches spreading in old trees and thus forming a broad round-topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. On panchromatic and black and white infrared photos bay is usually lighter in tone than adjacent conifer species but is very similar in appearance to most other hardwood species.

Salix sp.

(Willow)

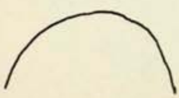
San Pablo Reservoir Test Area

Distribution: A widely distributed small tree or shrub of which about 50 species are native on the Pacific Coast. They inhabit stream banks and moist ground from sea level to alpine slopes of the highest mountains. The species is most common along the banks of creeks, gullies, and drainage ditches, growing any place where light and moisture conditions are favorable.

Soils: Grows on almost any soil, but its extensive shallow roots need an abundant and continuous supply of moisture during the growing season. It flourishes at or slightly below water level and is not appreciably damaged by flooding and silting.

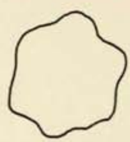
Assoc. Species: Valley oak, coast live oak, California bay, blue gum eucalyptus, Monterey pine, bigleaf maple, buckeye.

Crown apex:



rounded

Crown margin:



sinuate

Salix Sp.

Film: Aerial Ektachrome
Filter: None
Scale: 1/20,000
Date: September 1965

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/20,000
Date: June 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: May 1959

Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) A large shrub or small to medium deciduous tree, 6 to 40 feet high, often producing several trunks from a common root-crown. These multiple stems give the crown margin a lobed or wavy appearance. The crown apex is usually broadly rounded. On aerial ektachrome photography it appears light green and on ekta aero infrared photos it appears bright red. During the fall color change, its foliage turns brown before leaf drop and can easily be recognized on aerial ektachrome photography. On panchromatic and black and white infrared photography willow is usually lighter in tone than adjacent conifer species but is very similar in appearance to most other hardwood species.

Aesculus californica

(Buckeye)

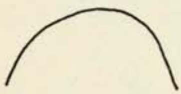
San Pablo Reservoir Test Area

Distribution: Common on dry slopes and in canyons below 4000 feet, in the Coast Ranges and Sierra Nevada from Siskiyou and Shasta counties to Los Angeles and Kern counties.

Soils: Can grow on a variety of soil types. Prefers deeper soils with adequate soil moisture, but is also very common on dry slopes with shallow soils throughout the range.

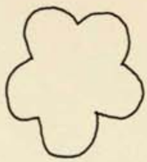
Assoc. Species: Coast live oak, valley oak, California bay, blue gum eucalyptus, Monterey pine, willow, bigleaf maple.

Crown apex:



rounded

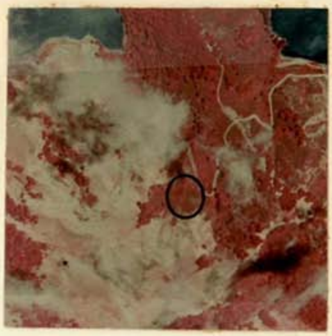
Crown margin:



lobed

Aesculus californica

Film: Aerial Ektachrome
Filter: None
Scale: 1/20,000
Date: September 1965



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/20,000
Date: June 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: August 1958

Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June 1965

Aerial Description: (See areas delineated above.) A very early deciduous tree, 15 to 40 feet high, with wide-spreading branches forming a rounded crown apex. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and very bright red on ekta aero infrared transparencies (highest infrared inflectance of all species studied). During the summer and early fall its leaves turn brownish-yellow. Its gnarled light toned branches are very distinct on late fall and winter photography. On panchromatic and black and white infrared photos buckeye is similar in appearance to most other deciduous hardwoods.

H21R

Mixed Hardwood

San Pablo Reservoir Test Area

Distribution: A widespread type common to the slopes and valleys of the Coast Ranges. Elevation, aspect, slope, and soil conditions are the major factors determining distribution. Hardwood vegetation is usually densest on moist shaded slopes. The existing stage of ecological succession on a given area will also regulate hardwood species composition.

Soils: The mixed hardwood type is found over an extensive area of varying soil conditions. Composition of a particular stand will be determined by particular soil type, parent material, texture, structure and moisture content.

Assoc. Species: Coast live oak, valley oak, California bay, Monterey pine, eucalyptus globulus, willow buckeye, bigleaf maple.

Crown apex:	Crown margin:
rounded (eucalyptus)	denticulate (eucalyptus)
rounded (buckeye)	lobed (buckeye)
rounded (live oak)	lobed (live oak)
rounded (willow)	sinuate (willow)
rounded (California bay)	lobed (California bay)

Mixed Hardwood

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: May, 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: May, 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/20,000
Date: August, 1958

Film: Infrared
Filter: Wratten 89B
Scale: 1/20,000
Date: June, 1965

Aerial Description: (See areas delineated above.) A variety of deciduous and hardwood trees ranging in height from 6 to 75 feet high. Crown margin and apex does not vary greatly between different species. Generally, the tree margins are lobed and apexes are rounded. A mixed conifer stand generally appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. Following the fall leaf drop, the deciduous species are easily recognized. On panchromatic photography, species composition within a stand is difficult to determine; however, adjacent conifer stands can usually be recognized. Hardwood stands are quite easily separated from mixed conifer stands on black and white infrared photography.

SUMMARY OF IDENTIFYING CHARACTERISTICS OF SIX CALIFORNIA FOREST SPECIES FOUND TO OCCUR IN THE SAN PABLO RESERVOIR AREA

Species	Tree Height	Color or Tone				Crown Detail		Soils	Remarks
		Ekta	Ekta IR	Pan	IR	Apex	Margin		
Pinus radiata	40-100 feet	dark-green	dark-red	dark-grey	dark-grey	obtuse	denticulate	deep, sandy loams	
Eucalyptus globulus	70-140 feet	blue-green	brownish red	dark-grey	dark-grey	rounded	denticulate	deep, moist loams	extensively cultivated
Quercus agrifolia	30-75 feet	light-green	bright-red	grey	grey	rounded	lobed	deep, well-drained	susceptible to attacks by oak-worm larvae
Umbellularia californica	30-75 feet	light-green	bright-red	grey	grey	rounded	lobed	deep, alluvial soils	
Salix sp.	6-40 feet	light-green	bright-red	grey	grey	rounded	sinuate	moist, alluvial	deciduous, riparian
Aesculus californica	15-40 feet	light-green	very bright-red	grey	grey	rounded	lobed	dry, varied depth	early deciduous

DICHOTOMOUS PHOTO INTERPRETATION KEY FOR SIX CALIFORNIA FOREST SPECIES FOUND TO OCCUR IN THE SAN PABLO RESERVOIR AREA (CHAPARRAL-HARDWOOD FOREST TYPE) - BASED ON PHOTOGRAPHY FLOWN TO OPTIMUM SPECIFICATIONS

1. Tall (>100 feet) trees with minutely sawtoothed (denticulate) crown margins. Generally dark-green on aerial Ektachrome transparencies, dark-red on Ekta Aero infrared transparencies and dark-grey on black-and-white panchromatic and infrared prints 2

1. Medium tall (<100 feet) trees with deeply rounded (lobed) or wavy (sinuate) crown margins. Generally light-green on aerial Ektachrome transparencies, bright-red on Ekta Aero infrared transparencies and grey on black-and-white panchromatic and infrared prints 3

2. Mature stands are dark-red on Ekta Aero infrared transparencies and crown apexes are bluntly rounded (obtuse)...Pinus radiata

2. Mature stands are brownish-red on Ekta Aero infrared transparencies and crown apexes are broadly rounded..Eucalyptus globulus

3. Trees are non-riparian; generally occurring on dry, well-drained soils 4

3. Trees are riparian; generally occurring on moist alluvial soils.... .... Salix sp.

4. Trees are evergreen 5

4. Trees are early deciduous and are very bright-red on Ekta Aero infrared transparencies ....Aesculus californica

5. Mature stands are light green on aerial Ektachrome transparencies and bright-red on Ekta Aero infrared transparencies ....Umbellularia californica

5. Mature stands are light-green on aerial Ektachrome transparencies and bright-red on Ekta Aero infrared transparencies. Trees are susceptible to attacks by a defoliating oakworm larvae...Quercus agrifolia

Pinus ponderosa

(Ponderosa Pine)

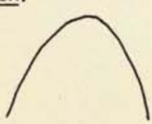
Meadow Valley Test Area

Distribution: Occurs in mixed conifer stands throughout the Sierra Nevada, from elevations of from 500 feet in the north to 7000 feet in the south. Pure stands exist on drier sites and are widely distributed throughout the east side of the Sierra.

Soils: The species is found on a variety of soils throughout its extensive range, including sandy, gravelly and silty loam, loamy sand, and gravel. Best growth is exhibited on well-drained, deep sandy, gravel and clay loams of medium texture.

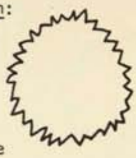
Assoc. Species: White fir, Douglas fir, sugar pine, lodgepole pine, incense cedar, California black oak, dogwood.

Crown apex:



obtuse

Crown margin:



denticulate

Pinus ponderosa

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 60 to 200 foot evergreen tree with a straight trunk. Spreading and slightly drooping branches form a broadly rounded to obtuse crown apex. The finely sawtoothed crown margin becomes obscured at scales of 1/5000 or smaller. The crown appears yellowish-green on aerial ektachrome and dark red on ekta aero infrared transparencies. A slight brownish cast due to needle die-back can be detected on aerial ektachrome photos taken in the fall. On panchromatic film, ponderosa pine is generally darker in tone than sugar pine and white fir but is very similar to all other coniferous species. Ponderosa pine is separated from incense cedar only by its superior height, occurrence in pure stands, or occurrence on drier sites.

Pinus contorta

(Lodgepole Pine)

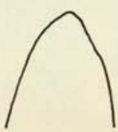
Meadow Valley Test Area

Distribution: Occurs around mountain meadows or on moist slopes, forming pure dense stands. It inhabits the Sierra Nevada from 6000 to 11,000 feet elevation in the south and central part and 5000 to 7500 feet in the north.

Soils: In the Sierra Nevada, the species is found mainly on wet flats and poorly drained soils. Soils with underlying hard-pans, which help to retain soil moisture in the root zone, often support good stands of lodgepole pine.

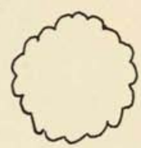
Assoc. Species: White fir, red fir, ponderosa pine, sugar pine, incense cedar, aspen, alder.

Crown apex:



ovate

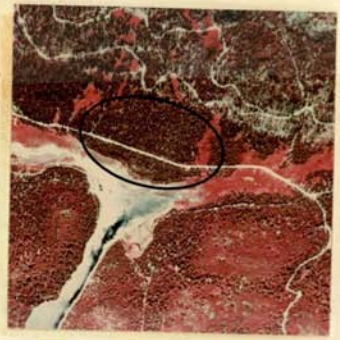
Crown margin:



crenate

Pinus contorta

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 30 to 80 foot evergreen tree with a straight but sometimes forked trunk. Short branches form a dense cylindrical crown with a bluntly pointed top. The crown margin appears almost entire at a scale of 1/5000 or smaller. The tree appears brownish-green on aerial ektachrome due to its foliage and exposed branches and understory. It appears greyish-red on ekta aero infrared transparencies. Neither panchromatic or black and white infrared photos provide sufficient clues for accurate identification of this species. Lodgepole pine is easily confused with medium sized ponderosa pine.

Pinus lambertiana

(Sugar Pine)

Meadow Valley Test Area

Distribution: Occurs mainly in mixed conifer stands on the western slopes of the Sierra Nevada from 3000 to 6000 feet in the north and from 5000 to 8000 feet in the south. Also occurs sparsely in the high regions of the Coast Range.

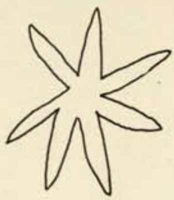
Soils: Occurs on many different soil types, from shallow stony or rocky clays to loose, deep, well-drained sandy loams. Best stands in the central Sierra grow on deep sandy loam soils.

Assoc. Species: White fir, red fir, Douglas fir, ponderosa pine, lodgepole pine, incense cedar, dgowood, California black oak.

Crown apex:

truncate

Crown margin:



parted

Pinus lambertiana

Film: Aerial Ektachrome
Filter: None
Scale: 1/2,500
Date: June 1964

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/5,000
Date: July 1964

Film: Panchromatic
Filter: Wratten 12
Scale: 1/2,500
Date: June 1964

Aerial Description: (See areas delineated above.) A 60 to 200 foot evergreen tree with a straight trunk. Huge branches spread outward horizontally and often form a flat-topped crown. The deeply parted, "star shaped" crown margin is the primary characteristic discernible on aerial photos and can be seen at scales as small as 1/10,000. Douglas fir has a similar crown margin but is darker in color or tone. Sugar pine appears whitish-green on aerial ektachrome and whitish-red on ekta aero infrared, similar to white fir. On panchromatic photos, both sugar pine and white fir are generally lighter in tone than most other coniferous species.

Abies magnifica

(Red Fir)

Meadow Valley Test Area

Distribution: Occurs on the western slopes of the Sierra Nevada and in the North Coast Ranges from 5000 to 9000 feet in elevation. Long winters with heavy snowpack and short dry summers are common in these areas. The species grows on protected steep slopes and on level areas where water from melting snow does not stand.

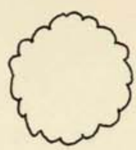
Soils: In the Sierra Nevada, red fir develops best on glacial moraines or on unglaciated areas with a deep soil. Stunted trees are found on exposed rocky slopes.

Assoc. Species: White fir, sugar pine, lodgepole pine.

Crown apex:

acute

Crown margin:



crenate

Abies magnifica

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: September 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: June 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed tip. The slightly irregular crown margin often appears entire on scales of 1/5,000 or smaller. The tree appears whitish-green on aerial ektachrome and whitish-red on ekta aero infrared transparencies. On panchromatic photos, red fir is generally lighter in tone than most other coniferous species. A heavy cone crop in the top of the tree crown is often discernible on fall photography.

Abies concolor

(White Fir)

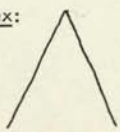
Meadow Valley Test Area

Distribution: Occurs in pure stands on moist sites or in mixed conifer stands throughout the Sierra Nevada. Most white fir in California is found at 4000 to 7000 foot elevations along the western Sierra Nevada. Usually it grows on north slopes and in some places is fairly abundant on benches and sides of moist canyons.

Soils: Though the species is found on a variety of soils, the deeper and more permeable soils, when supplied with adequate moisture, are most conducive to good growth. In the mixed conifer type of the northern Sierra, the best growth is found on loam or sandy loam soils.

Assoc. Species: Red fir, Douglas fir, ponderosa pine, sugar pine, lodgepole pine, incense cedar, California black oak, dogwood.

Crown apex:



acute

Crown margin:

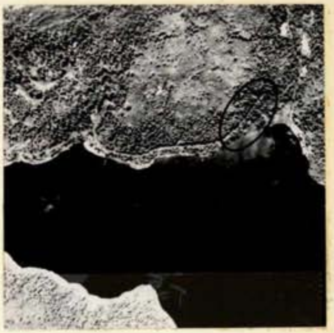
crenate

Abies concolor

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965



Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed top. The slightly irregular crown margin often appears entire at scales of 1/5000 or smaller. The tree appears whitish-green on aerial ektachrome and whitish-red on ekta aero infrared transparencies, similar to sugar pine. On panchromatic photos, both white fir and sugar pine are generally lighter in tone than most other coniferous species. A heavy cone crop in the top of the tree crown is often discernible on fall photography.

Pseudotsuga menziesii

(Douglas Fir)

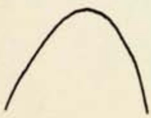
Meadow Valley Test Area

Distribution: Occurs in pure stands or associated with coast redwood in the Coast Ranges from Del Norte County southward to Monterey County from sea level to 4000 feet. Individual trees occur in mixed conifer stands throughout the northern and central Sierra Nevada from 2500 to 6000 feet.

Soils: Grows best on loose, well-drained soils. In the Sierra Nevada region the species is most closely associated with northerly slopes and moist canyon bottoms.

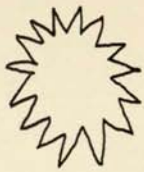
Assoc. Species: White fir, sugar pine, ponderosa pine, incense cedar, California black oak and dogwood.

Crown apex:



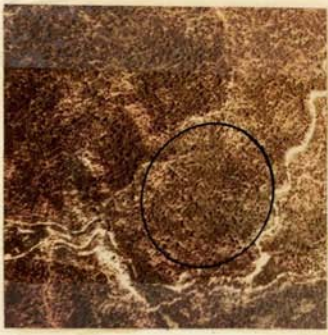
obtuse

Crown margin:

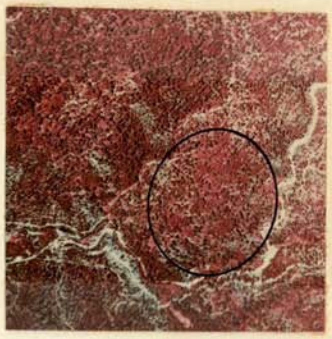


dentate

Pseudotsuga menziesii



Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: June 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 70 to 250 foot evergreen tree with a straight trunk. Irregular whorled branches spread horizontally with pendulous branchlets forming a deeply sawtoothed crown margin. The deeply parted crown margin of sugar pine and dentate margin of Douglas fir can be confused. Douglas fir appears blue-green on aerial ektachrome and dark red on ekta aero infrared transparencies. On panchromatic photos, Douglas fir is generally darker in tone than sugar pine or white fir but very similar to most other coniferous species.

Libocedrus decurrens

(Incense Cedar)

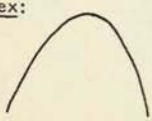
Meadow Valley Test Area

Distribution: Trees occur in mixed conifer stands in the higher Coast Ranges, the Sierra Nevada and the mountains of southern California. In the central Sierra Nevada, where the best stands occur, the species is found between 2000 and 7000 feet elevation. It is more common on drier west-facing than on east-facing mountain slopes.

Soils: In the Sierra Nevada, the species grows best on deep, slightly to moderately acid, sandy loam soils. It is also common on shallow, rocky soils developed from serpentine rock where it grows better than other conifer types.

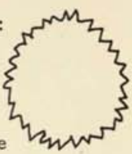
Assoc. Species: White fir, Douglas fir, sugar pine, ponderosa pine, California black oak, dogwood.

Crown apex:



obtuse

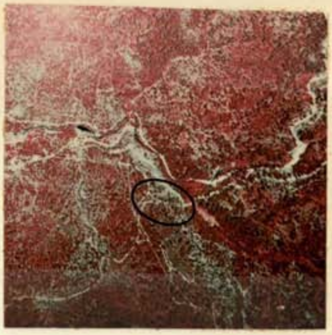
Crown margin:



denticulate

Libocedrus decurrens

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/10,000
Date: June 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 50 to 150 foot tree with a tapering trunk from a thick base. Spreading and slightly drooping branches form a broadly rounded to obtuse crown apex. The finely sawtoothed crown margin becomes obscured at scales of 1/5,000 or smaller. The tree appears yellowish-green on aerial ektachrome and dark red on ekta aero transparencies. On panchromatic film, incense cedar is generally darker in tone than sugar pine and white fir but is very similar to most other coniferous species. No photography allows accurate separation of incense cedar from ponderosa pine. However, mature cedars are often spike topped and very yellow-green on color photography.

Mixed Conifer

Meadow Valley Test Area

Distribution: Extensive continuous forests in the Sierra Nevada having an elevational range from 2000 to 6500 or 7000 feet. Composition of these forests (see species below) varies widely according to elevation, aspect, slope, and soil condition.

Soils: The mixed conifer type is found over an extensive area of varying soil conditions. Composition of a particular forest stand will be determined by particular soil type, parent material, texture, structure, and moisture content.

Assoc. Species: White fir, Douglas fir, ponderosa pine, sugar pine, incense cedar.

Crown apex:

truncate (sugar pine)
obtuse (ponderosa pine)
acute (white fir)
obtuse (Douglas fir)
obtuse (incense cedar)

Crown margin:

parted (sugar pine)
denticulate (ponderosa pine)
crenate (white fir)
dentate (Douglas fir)
denticulate (incense cedar)

Mixed Conifer

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: June 1965

Aerial Description: (See areas delineated above.) A variety of straight trunk evergreen trees ranging in height from 50 to 250 feet high. Crown margin will vary greatly depending upon the species. Similarly, each crown apex may vary from acute for white fir to truncate for sugar pine. A mixed conifer stand generally appears dark green on aerial ektachrome and dark red on ekta aero infrared transparencies. On panchromatic photography, species composition within a stand is difficult to determine; however, adjacent hardwood stands can usually be recognized. Such hardwood stands are quite easily separated from mixed conifer stands on black and white infrared photography.

Quercus kelloggii

(California Black Oak)

Meadow Valley Test Area

Distribution: Occurs on lower and middle mountain slopes and foothills of the Coast Ranges and the Sierra Nevada. The species is commonly associated with the mixed conifer forest on the western flank of the Sierra, scattered among conifers on slopes and forming oak woodlands in some flat valleys. Concentrations of black oak are most prominent on the drier south facing slopes. The species is found from 3000 to 5000 feet in elevation in the northern Sierra.

Soils: It is common on dry, well-drained slopes having low soil moisture, especially south-facing slopes. The species is found on a variety of soils, including sandy and gravelly loam, loamy sand and loam.

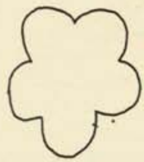
Assoc. Species: White fir, Douglas fir, ponderosa pine, sugar pine, incense cedar, dogwood.

Crown apex:

rounded

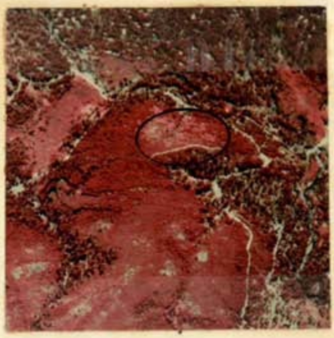
Crown margin:

lobed



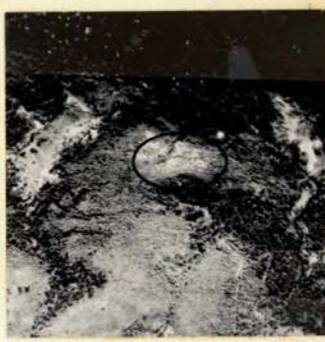
Quercus kelloggii

Film: Aerial Ektachrome
Filter: None
Scale: 1/25,000
Date: September 1965



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/25,000
Date: June 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965



Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A 30 to 80 foot deciduous tree with stout spreading branches forming a broad round-topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. During fall coloration it appears yellow to yellow-green on aerial ektachrome and grey to pink on ekta aero infrared. Black oak can only be recognized as a hardwood on panchromatic photos but with difficulty. However, this distinction is easily made on black and white infrared photography.

Acer macrophyllum

(Bigleaf Maple)

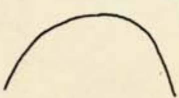
Meadow Valley Test Area

Distribution: Native to Pacific Coast Mountains from British Columbia to southern California. In California the species is most abundant below elevations of 5500 feet. In this part of the range the species is almost always found near permanent water courses. Its distribution is usually limited to stream banks and other moist areas.

Soils: Grows on a variety of soils throughout its range, from deep loams to thin soils on rocky slopes. It makes its best development on rich bottomlands near rivers and streams.

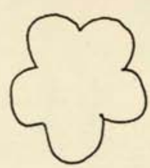
Assoc. Species: White fir, Douglas fir, ponderosa pine, sugar pine, willow, dogwood, incense cedar.

Crown apex:



rounded

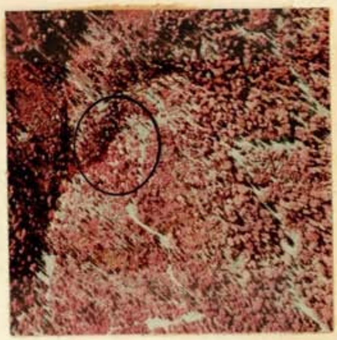
Crown margin:



lobed

Acer macrophyllum

Film: Aerial Ektachrome
Filter: None
Scale: 1/10,000
Date: September 1965



Film: Ekta Aero Infrared
Filter: Wratten 12
Scale: 1/10,000
Date: September 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/10,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: September 1965

Aerial Description: (See areas delineated above.) A medium-sized or large deciduous tree, 30 to 100 feet high with stout spreading branches forming a broad round-topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. Generally the tree appears light green on aerial ektachrome and very bright red on ekta aero infrared transparencies. Maple is most easily identified on fall photography when its foliage appears bright yellow on ektachrome and pale white on ekta aero infrared photography. On panchromatic photography the species is difficult to identify from most other species. On black and white infrared photography it is lighter in tone than adjacent conifer species but is very similar in appearance to most other hardwood species.

Populus trichocarpa

(Black Cottonwood)

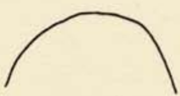
Meadow Valley Test Area

Distribution: Native to the Pacific Coast from southern Alaska to southern California, inhabiting stream banks and moist bottomlands of valleys of the mountainous regions from 3000 to 6000 feet.

Soils: Grows in soils ranging from moist gravels and sands to rich humus soils. At higher elevations, the species grows in moist sandy, gravelly or loam soils. Since it demands abundant moisture in drier areas, it grows in canyon bottoms, along stream banks and edges of ponds and meadows where the roots can reach a relatively permanent supply of soil moisture.

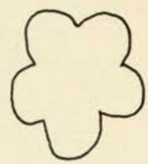
Assoc. Species: White fir, red fir, ponderosa pine, sugar pine, lodgepole pine, incense cedar, aspen, alder, willow, maple.

Crown apex:



rounded

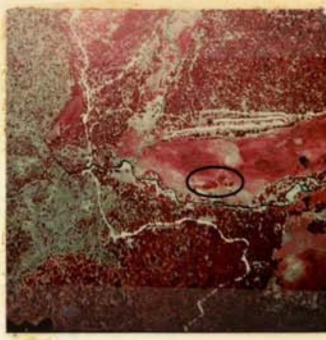
Crown margin:



lobed

Populus trichocarpa

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: June 1965

Aerial Description: (See areas delineated above.) A tall deciduous tree, 40 to 100 feet high with ascending or spreading branches forming a rather broadly rounded or flat-topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. During fall coloration it appears yellow to yellow-green on aerial ektachrome and grey to pink on ekta aero infrared. Cottonwood can only be recognized with difficulty as a hardwood species on panchromatic photos. However, this distinction is easily made on black and white infrared photography.

Alnus tenuifolia

(Mountain Alder)

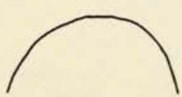
Meadow Valley Test Area

Distribution: A shrub or small tree whose range extends from British Columbia to Lower California. It is native to the Rockies, the Cascades and the Sierra Nevada. In the Sierra Nevada, this species is the common alder of stream banks, moist flats and high mountain meadows and is usually found at elevations of from 4500 to 8000 feet.

Soils: Grows on soils varying from gravel or sand to clay. The species shows best growth on well-drained loams or loamy sands. Since moisture requirements are high, alder grows best in meadows or on banks of permanent watercourses.

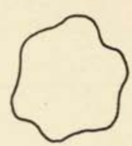
Assoc. Species: White fir, red fir, ponderosa pine, sugar pine, incense cedar, aspen, willow, cottonwood.

Crown apex:



rounded

Crown margin:



sinuate

H3N

Alnus tenuifolia

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: September 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: June 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A large shrub or small to medium deciduous tree, 5 to 20 feet high, often producing several trunks from a common root-crown. These multiple stems give the crown margin a lobed or wavy appearance. The crown apex is usually broadly rounded. On aerial ektachrome photography it appears bright green and is very similar in appearance to willow. On ekta aero infrared photos the alder appears as a brighter red than the willow and can usually be identified. During the fall color change its foliage turns brown before leaf drop and can easily be recognized on aerial ektachrome photography. Alder can be recognized only with difficulty as a hardwood species on panchromatic photos; however, this distinction is easily made on black and white infrared photography.

Populus tremuloides

(Quaking Aspen)

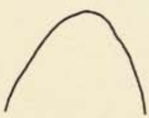
Meadow Valley Test Area

Distribution: Native in the colder mountain regions of North America. In California it is most abundant between elevations of 6000 and 10,000 feet where it occurs mainly on cool, shaded mountain slopes, in canyons and along streams. It also occurs on the borders of mountain meadows, lakes and moist benches.

Soils: Grows on a great variety of soils ranging from shallow rocky soils and loamy sands to heavy clays. Moisture conditions are favorable if the ground water level occurs between 18 inches and 5 feet below the surface. Heavy clays do not prompt the best growth because of poor aeration.

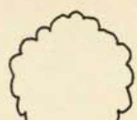
Assoc. Species: Red fir, white fir, Douglas fir, lodgepole pine, ponderosa pine, sugar pine and alder.

Crown apex:



obtuse

Crown margin:



crenate

Populus tremuloides

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A small slender deciduous tree, 10 to 60 feet high with a straight trunk. Short branches form a dense cylindrical crown with a bluntly pointed to obtuse crown apex. The crown margin appears notched with rounded teeth. However, at a scale of 1/5000 or smaller, this pattern becomes obscured and the margin appears almost entire. Generally, the tree appears light green on aerial ektachrome and bright red on ekta aero infrared transparencies. During fall coloration it appears yellow to yellow-green on aerial ektachrome and grey to pink on ekta aero infrared. On panchromatic photography the species is very difficult to discern from most other species. On black and white infrared photography it is lighter in tone than the conifers and is similar in tone to the other hardwood species.

Salix sp.

(Willow)

Meadow Valley Test Area

Distribution: A widely distributed small tree or shrub of which about 50 species are native to the Pacific Coast. They inhabit stream banks and moist ground from sea level to alpine slopes of the highest mountains. The species is most common on the banks of creeks, gullies and drainage ditches, growing any place where light and moisture conditions are favorable.

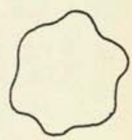
Soils: Grows on almost any soil, but its extensive, shallow roots need an abundant and continuous supply of moisture during the growing season. It flourishes at or slightly below water level and is not appreciably damaged by flooding and silting.

Assoc. Species: Alder, cottonwood, maple, red fir, white fir, Douglas fir, lodgepole pine, ponderosa pine and incense cedar.

Crown apex:

rounded

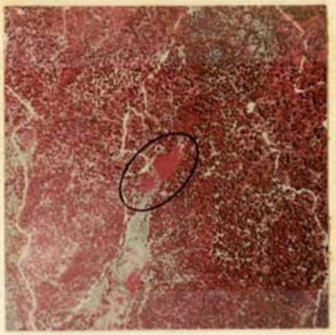
Crown margin:



sinuate

Salix sp.

Film: Aerial Ektachrome
Filter: None
Scale: 1/28,000
Date: June 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/28,000
Date: June 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/25,000
Date: June 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/25,000
Date: June 1965

Aerial Description: (See areas delineated above.) A large shrub or small to medium deciduous tree, 6 to 40 feet high, often producing several trunks from a common root-crown. These multiple stems give the crown margin a lobed or wavy appearance. The crown apex is usually broadly rounded. On aerial ektachrome photography it appears bright green and is very similar in appearance to alder. On ekta aero infrared photos the willow is not as bright as the alder and can usually be identified. During the fall color change, its foliage turns brown before leaf drop and can easily be recognized on aerial ektachrome photography. Willow can only be recognized with difficulty as a hardwood species on panchromatic photos. However, this distinction is easily made on black and white infrared photography.

Cornus nuttallii

(Pacific Dogwood)

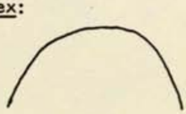
Meadow Valley Test Area

Distribution: Native in the coastal mountains from British Columbia to southern California and on the western slope of the Sierra Nevada from 2500 feet to 5100 feet. Generally found on north-facing slopes where adequate soil moisture is available.

Soils: Grows best on deep, well-drained loamy soils. Requires adequate soil moisture for good growth. Therefore the species is infrequently found on dry exposures but prefers moist sheltered slopes.

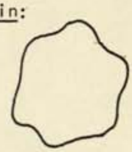
Assoc. Species: White fir, Douglas fir, ponderosa pine, sugar pine, incense cedar, California black oak.

Crown apex:



rounded

Crown margin:



sinuate

Cornus nuttallii

Film: Aerial Ektachrome
Filter: None
Scale: 1/10,000
Date: September 1965

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/10,000
Date: September 1965

Film: Panchromatic
Filter: Wratten 12
Scale: 1/10,000
Date: September 1965

Film: Infrared
Filter: Wratten 89B
Scale: 1/10,000
Date: September 1965

Aerial Description: (See areas delineated above.) A small to medium deciduous tree, 10 to 40 feet high, often producing several trunks from a common root crown. These multiple stems give the crown margin a lobed or wavy appearance. The crown apex is usually broadly rounded. On aerial ektachrome photography, it appears bright green. On ekta aero infrared photos it appears bright red. During the fall color change its foliage turns red before leaf drop and can easily be recognized on aerial ektachrome. On the ekta aero infrared, the red foliage appears bright yellow-orange. Identification of this species is difficult on panchromatic and black and white infrared photos.

SUMMARY OF IDENTIFYING CHARACTERISTICS OF FOURTEEN CALIFORNIA FOREST SPECIES FOUND TO OCCUR IN THE BUCKS LAKE-MEADOW VALLEY AREA

Species	Tree Height	Color or Tone				Crown Detail		Soils	Remarks
		Ekta	Ekta IR	Pan	IR	Apex	Margin		
Pinus ponderosa	60-200 feet	yellow-green	dark-red	dark-grey	dark-grey	obtuse	denticulate	variety of deep, well-drained loams	annual needle die-back in the fall
Pinus contorta	30-80 feet	brownish-green	greyish-red	dark-grey	dark-grey	ovate	crenate	wet flats, poorly drained	
Pinus lambertiana	60-200 feet	whitish-green	whitish-red	grey	grey	truncate	parted	variety of deep well-drained loams	
Abies magnifica	60-200 feet	whitish-green	whitish-red	grey	grey	acute	crenate	moraines, deep	high elevation, cone crop in fall
Abies concolor	60-200 feet	whitish-green	whitish-red	grey	grey	acute	crenate	variety of deep, well-drained loams	cone crop in the fall
Pseudotsuga menziesii	70-250 feet	blue-green	dark-red	dark-grey	dark-grey	obtuse	dentate	loose, well-drained	
Libocedrus decurrens	50-150 feet	yellow green	dark-red	dark-grey	dark-grey	obtuse	denticulate	variety of deep acid loams	often on serpentine soils
Quercus kelloggii	30-80 feet	light-green	bright-red	grey	light-grey	rounded	lobed	variety of dry loams	deciduous

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SUMMARY OF IDENTIFYING CHARACTERISTICS OF FOURTEEN CALIFORNIA FOREST SPECIES FOUND TO OCCUR IN THE BUCKS LAKE-MEADOW VALLEY AREA (con't)

Species	Tree Height	Color or Tone				Crown Detail		Soils	Remarks
		Ekta	Ekta IR	Pan	IR	Apex	Margin		
Acer macrophyllum	30-100 feet	light-green	very bright red	grey	light-grey	rounded	lobed	moist, alluvial	deciduous, riparian, bright fall color
Populus trichocarpa	40-100 feet	light-green	very bright red	grey	light-grey	rounded	lobed	moist, alluvial	deciduous, riparian
Alnus tenuifolia	5-20 feet	light-green	bright red	grey	light-grey	rounded	sinuate	moist, alluvial	deciduous, riparian
Populus tremuloides	10-80 feet	light-green	verybright red	grey	light grey	obtuse	crenate	moist, alluvial	deciduous, riparian, bright fall coloring
Salix sp.	6-40 feet	light-green	bright-red	grey	light-grey	rounded	sinuate	moist, alluvial	deciduous, riparian
Cornus nuttallii	10-40 feet	light-green	bright-red	grey	light-grey	rounded	sinuate	dry, varied depth	deciduous, bright fall coloring

DICHOTOMOUS PHOTO INTERPRETATION KEY FOR
FOURTEEN CALIFORNIA FOREST SPECIES FOUND TO OCCUR
IN THE BUCKS LAKE-MEADOW VALLEY AREA (MIXED CONIFER FOREST TYPE);
BASED ON PHOTOGRAPHY FLOWN TO OPTIMUM SPECIFICATIONS

1. Tall (>100 feet) evergreen trees with bluntly rounded (obtuse) to pointed (acute) crown apexes....................................2

1. Medium tall (<100 feet) deciduous trees with broadly rounded crown apexes..8

    2. Crown apexes are sharply pointed...............................3

    2. Crown apexes are bluntly rounded...............................4

3. Mature stands are whitish-green on aerial Ektachrome transparencies and whitish-red on Ekta Aero infrared transparencies. Cone crop is often discernible in the Fall.._Abies concolor_

3. Mature stands are whitish-green on aerial Ektachrome transparencies and whitish-red on Ekta Aero infrared transparencies. Cone crop is often discernible in the Fall. Generally is found at higher elevations........._Abies magnifica_

    4. Trees often taller than 100 feet. Mature stands are yellow-green or whitish-green on aerial Ektachrome transparencies. Generally is found on a variety of well-drained soils...5

    4. Trees rarely taller than 100 feet. Mature stands are brownish-green on aerial Ektachrome transparencies. Generally is found on wet flats or poorly drained soils.._Pinus contorta_

5. Mature stands are yellow-green or blue-green on aerial Ektachrome transparencies and dark-red on Ekta Aero infrared transparencies. Crown margins are minutely sawtoothed (denticulate) or deeply sawtoothed (dentate)..............6

5. Mature trees are whitish-green on aerial Ektachrome transparencies and whitish-red on Ekta Aero infrared transparencies. Crown margins are deeply parted.....<u>Pinus</u> <u>lambertiana</u>

   6. Mature stands are yellow-green on aerial Ektachrome transparencies. Crown margins are minutely sawtoothed (denticulate)..7

   6. Mature stands are blue-green on aerial Ektachrome transparencies. Crown margins are deeply sawtoothed (dentate)........................<u>Pseudotsuga</u> <u>menziesii</u>

7. Mature stands rarely occur on serpentine soils.........<u>Pinus</u> <u>ponderosa</u>

7. Mature stands often occur on serpentine soils.....<u>Libocedrus</u> <u>decurrens</u>

   8. Trees are non-riparian; generally occuring on dry, well-drained soils..................................9

   8. Trees are riparian; generally occuring on moist alluvial soils..10

9. Trees often taller than 40 feet. Mature stands are bright yellow or brownish-red during fall color change..<u>Quercus</u> <u>kelloggii</u>

9. Trees rarely taller than 40 feet. Mature stands are bright-red during fall color change..............<u>Cornus</u> <u>nuttallii</u>

   10. Trees often taller than 40 feet................................11

   10. Trees rarely taller than 40 feet.................<u>Alnus</u> <u>tenuifolia</u> and <u>Salix</u> <u>sp.</u>

11. Crown apexes are broadly rounded and crown margins are deeply rounded (lobed)............................<u>Acer macrophyllum</u> and <u>Populus trichocarpa</u>

11. Crown apexes are bluntly rounded (obtuse) and crown margins are notched with rounded teeth (crenate)...<u>Populus tremuloides</u>

Quercus lobata

(Valley Oak)

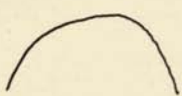
Geysers Test Area

Distribution: Native in the fertile parts of the Sacramento, San Joaquin and adjacent valleys, the foothills of the Sierra Nevada, the inner and middle Coast Ranges and extending south to the San Fernando Valley, but not in valleys facing the sea. Found on valleys and slopes below 2000 feet elevation.

Soils: Prefers rich loams of valley floors and slopes and grows best where soil is deep and well-watered.

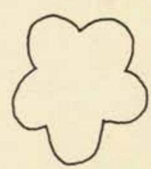
Assoc. Species: Coast live oak, California bay, blue gum eucalyptus, Monterey pine, willow, bigleaf maple, buckeye.

Crown apex:



rounded

Crown margin:



lobed

Quercus lobata

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

Aerial Description: (See areas delineated above.) A large deciduous tree, 40 to 125 feet high, with ascending or spreading and ultimately drooping branches forming a broad round-topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. The tree appears light green on aerial ektachrome and pinkish-red on ekta aero infrared transparencies. During fall coloration it appears yellow to yellow-green on aerial ektachrome and grey to pink on ekta aero infrared. On panchromatic and black and white infrared photos it is lighter in tone than adjacent conifer species but is very similar in appearance to most other hardwood species.

Acer macrophyllum

(Bigleaf Maple)

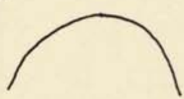
Geysers Test Area

Distribution: Native to the mountains of the Pacific Coast from British Columbia to southern California. In California the species is most abundant below elevations of 5500 feet. In this part of the range the species is almost always found near permanent watercourses. Its distribution is usually limited to stream banks, canyon bottoms, and other moist areas.

Soils: Grows on a variety of soils throughout its range, from deep loams to thin soils on rocky slopes. It makes its best development on rich bottomlands near rivers and streams.

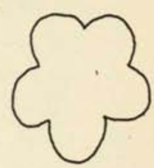
Assoc. Species: Coast live oak, valley oak, California bay, blue gum eucalyptus, Monterey pine, willow, buckeye.

Crown apex:



rounded

Crown margin:



lobed

Acer macrophyllum

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

Aerial Description: (See areas delineated above.) A medium-sized or large deciduous tree, 30 to 100 feet high with stout spreading branches forming a broad round-topped crown. The foliage on each branch gives the crown margin a lobed or billowing appearance. Generally the tree appears deep green on aerial ektachrome and very bright red on ekta aero infrared transparencies. Maple is most easily identified on fall photography when its foliage appears bright yellow on ektachrome and pale white on ekta aero infrared photography. On panchromatic and black and white infrared photos it is lighter in tone than adjacent conifer species but is very similar in appearance to most other hardwood species.

Cuppressus sargenti

(Sargent Cypress)

Geysers Test Area

Distribution: Native on the dry mountain slopes and valleys of the Santa Lucia, Santa Cruz, and San Rafael Mountains and of Marin, Sonoma, Napa, Lake and Mendocino Counties of California.

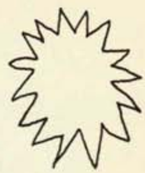
Soils: Prefers dry, exposed soils of mountain slopes and valleys. Best growth exhibited on well-drained soils.

Assoc. Species: Knobcone pine, ponderosa pine, digger pine, Douglas fir.

Crown apex:

truncate

Crown margin:



dentate

<u>Cuppressus sargenti</u>

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

<u>Aerial Description</u>: (See areas delineated above.) A small tree, 10 to 40 feet high, or sometimes shrub-like, with erect or spreading branches forming an open flat-topped crown apex. The deeply parted crown margin is similar to that of sugar pine or Douglas fir. The tree appears grey-green on aerial ektachrome and lavender on ekta aero infrared transparencies. On panchromatic and black and white infrared photos cypress can be identified as a coniferous species but usually with difficulty.

Pinus sabiniana

(Digger Pine)

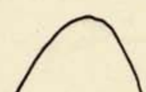
Geysers Test Area

Distribution: Native on the dry foothills and lower mountain slopes of northern anc central California, from 100 to 3000 feet elevation (5000 feet in the south).

Soils: Usually found on dry, well drained soils of slopes and valleys of foothill areas.

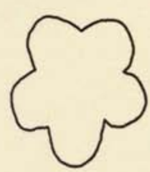
Assoc. species: Knobcone pine, ponderosa pine, Douglas-fir, Sargent Cypress.

Crown apex:



obtuse

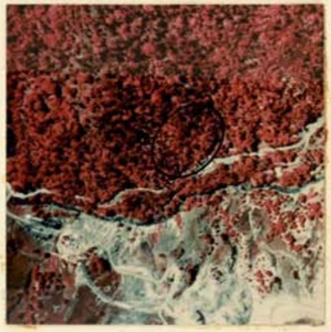
Crown margin:



lobed

Pinus sabiniana

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

Aerial Description: (See areas delineated above.) A 40 to 80 foot evergreen tree with the main trunk usually divided into two or more secondary trunks. These multiple stems give the crown margin a lobed or billowy appearance. The tree appears grey-green on aerial ektachrome and whitish-red on ekta aero infrared transparencies. On panchromatic photos it is generally lighter in tone than most other coniferous species; however, on black and white infrared it is quite similar to the associated conifers.

Pseudotsuga menziesii

(Douglas-fir)

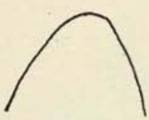
Geysers Test Area

Distribution: Occurs in pure stands or associated with coast redwood in the Coast Ranges from Del Norte County southward to Monterey County from sea level to 4000 feet. Individual trees occur in mixed conifer stands throughout the northern and central Sierra Nevada from 2500 to 6000 feet.

Soils: Grows best on loose, well-drained soils. In the southern part of the range, the species occurs mainly on protected northerly slopes and in canyon bottoms with high soil moisture content.

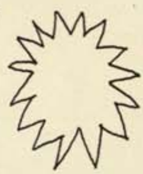
Assoc. Species: Knobcone pine, digger pine, ponderosa pine, Sargent cypress.

Crown apex:



obtuse

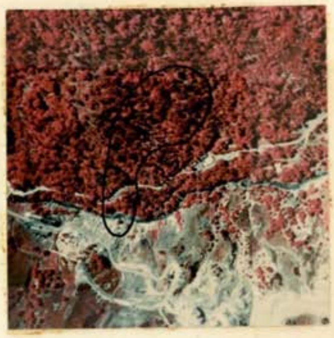
Crown margin:



dentate

Pseudotsuga menziesii

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966



Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

Aerial Description: (See areas delineated above.) A 70 to 250 foot evergreen tree with a straight trunk. Irregular whorled branches spread horizontally with pendulous branchlets forming a deeply sawtoothed crown margin. The tree appears blue-green on aerial ektachrome and dark red on ekta aero infrared transparencies. On panchromatic photos, Douglas-fir is generally darker in tone than digger pine or knobcone pine but very similar to redwood.

Pinus attenuata

(Knobcone Pine)

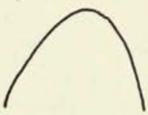
Geysers Test Area

Distribution: Native on rocky slopes and ridges in scattered localities in southern Oregon and, in California, in the Coast Ranges and the Sierra Nevada.

Soils: Prefers dry, well-drained soils of slopes and ridges of foothills. Frequently found on exposed shallow soils.

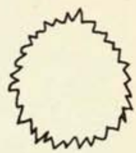
Assoc. Species: Digger pine, ponderosa pine, Douglas-fir, Sargent cypress.

Crown apex:



obtuse

Crown margin:



denticulate

Pinus attenuata

Film: Aerial Ektachrome
Filter: None
Scale: 1/12,000
Date: April 1966

Film: Ekta Aero Infrared
Filter: Wratten 12 + EF-2200
Scale: 1/12,000
Date: April 1966

Film: Panchromatic
Filter: Wratten 12
Scale: 1/12,000
Date: April 1966

Film: Infrared
Filter: Wratten 89B
Scale: 1/12,000
Date: April 1966

Aerial Description: (See areas delineated above.) A slender tree, 10 to 40 (rarely to 80) feet high, with ascending or spreading branches forming an open, rounded to obtuse crown apex. The finely sawtoothed crown margin becomes obscured at scale of 1/5,000 or smaller. The crown appears yellowish-green on aerial ektachrome and dark red on ekta aero infrared transparencies. On panchromatic and black and white infrared photos it can be separated from adjacent hardwood stands but to separate from other coniferous species is difficult. Knobcone pine often occurs in very dense, even-aged stands following fire or logging.

SUMMARY OF IDENTIFYING CHARACTERISTICS OF SIX CALIFORNIA FOREST SPECIES FOUND TO OCCUR IN THE RUSSIAN RIVER DRAINAGE OF THE COAST RANGE

Species	Tree Height	Color or Tone				Crown Detail		Soils	Remarks
		Ekta	Ekta-IR	Pan	IR	Apex	Margin		
Quercus lobata	40-125 feet	light-green	pinkish-red	light-grey	light-grey	rounded	lobed	deep, rich loams	deciduous
Acer macrophyllum	30-100 feet	dark-green	bright-red	dark-grey	light-grey	rounded	lobed	rich bottomlands of varied depth	deciduous, bright fall color
Cuppressus sargenti	10-40 feet	grey-green	lavender	grey	grey	truncate	dentate	dry, exposed, well-drained	
Pinus sabiniana	40-80 feet	grey-green	whitish-red	light-grey	light-grey	obtuse	lobed	dry, well-drained	
Pseudotsuga menziesii	70-250 feet	blue-green	dark-red	dark-grey	dark-grey	obtuse	lobed	loose, well-drained	
Pinus attenuata	10-40 feet	yellow-green	dark-red	dark-grey	dark-grey	obtuse	denticulate	dry, well-drained, exposed	often in dense, even-aged stands

DICHOTOMOUS PHOTO INTERPRETATION KEY FOR SIX CALIFORNIA TREE SPECIES FOUND TO OCCUR IN THE RUSSIAN RIVER DRAINAGE OF THE COAST RANGE (CHAPARRAL-HARDWOOD FOREST TYPE); BASED ON PHOTOGRAPHY FLOWN TO OPTIMUM SPECIFICATIONS

Deciduous trees with broad round-topped crown apexes giving a lobed or billowy appearance. Generally bright red or pink on Ekta Aero Infrared transparencies and light grey on infrared prints................ 2

1. Evergreen trees with obtuse or truncate crown apexes giving a dense compact appearance. Generally dark red on Ekta Aero Infrared transparencies and dark grey on infrared prints..........................3

    2. Mature stands are pinkish-red on Ekta Aero Infrared transparencies and light grey on panchromatic prints.................. *Quercus lobata*

    2. Mature stands are bright-red on Ekta Aero Infrared transparencies and dark grey on panchromatic prints................ *Acer macrophyllum*

3. Mature stands are grey-green on aerial Ektachrome transparencies and lavender or whitish-red on Ekta Aero Infrared transparencies. Generally are light grey on panchromatic and infrared prints.............4

3. Mature stands are blue-green or yellow-green on aerial Ektachrome and dark red on Ekta Aero Infrared transparencies. Generally are light dark grey on panchromatic and infrared prints......................5

    4. Mature stands are lavender on Ekta Aero Infrared transparencies. Crown apexes are flat topped (truncate) and crown margins are deeply parted (dentate)........................... *Cuppressus sargenti*

    4. Mature stands are whitish-red on Ekta Aero Infrared transparencies. Crown apexes are bluntly pointed (obtuse) and crown margins are deeply rounded (lobed).............................. *Pinus sabiniana*

5. Mature stands are 70-250 feet high and appear blue-green on aerial Ektachrome transparencies. Crown margins are deeply rounded (lobed). Rarely occur in dense even-aged stands..<u>Pseudotsuga menziesii</u>

5. Mature stands are 10-40 feet high and appear yellow-green on aerial Ektachrome transparencies. Crown margins are finely sawtoothed (denticulate). Often occur in dense even-aged stands..<u>Pinus attenuata</u>

APPENDIX II - PHOTO INTERPRETATION TEST

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PHOTO INTERPRETATION TEST

The objective of the photo interpretation test is to determine if six major species occurring in the Sierra Nevada mixed conifer belt can be identified on large-scale, low-altitude aerial photographs flown to optimum specifications. The 150 test trees were identified by three interpreters on aerial Ektachrome transparencies at scales of 1/5000 and 1/2,500, on Ekta Aero Infrared transparencies at 1/5,000 and on panchromatic prints at 1/2,500. Interpretation accuracy in relation to photo interpretation experience was studied by comparing results of two experienced forest photo interpreters (#1 and #2) and one sixth grade teacher (#3) with no interpretation experience.

Each of the interpreters identified the same population of trees and followed a procedure prescribed in the following instructions:

Instructions for Photo Interpretation Test

I. Training Period
   - A. Study each of the six tree descriptions
   - B. Examine key trees (circled) in areas A and B with reference to tree descriptions on:
     1) Ektachrome, 1/2,500
     2) Panchromatic, 1/2,500
     3) Ekta Aero Infrared, 1/5,000
     4) Ektachrome, 1/5,000
   - C. Identify example trees (squared) in areas A and B with reference to the dichotomous key and the tree description on:
     1) Ektachrome, 1/5,000
     2) Ekta Aero Infrared, 1/5,000
     3) Panchromatic, 1/2,500
     4) Ektachrome, 1/2,500
   - D. Check results and review

II. Interpretation of Ektachrome, 1/5,000
   - A. Review each tree description
   - B. Review key trees and example trees in areas A and B
   - C. Identify test trees in areas A, B and C

III. Interpretation of Ekta Aero Infrared, 1/5,000
   A. Review each tree description
   B. Review key trees and example trees in areas A and B
   C. Identify test trees in areas A, B and C
IV. Interpretation of panchromatic, 1/2,500
   A. Review each tree description
   B. Review key trees and example trees in areas A and B
   C. Identify test trees in areas A, B and C
V. Interpretation of Ektachrome, 1/2,500
   A. Review each tree description
   B. Review trees and example trees in areas A and B
   C. Identify test trees in areas A, B and C

The importance of using the photo interpretation key throughout the training period and immediately prior to each interpretation period was stressed. Interpreters were instructed not to begin identifying test trees until they were thoroughly acquainted with each species.

Tables A and B summarize interpretation results. The figures in Table A indicate percentage of correctly identified trees per species (omission error). Results for each interpreter have been tallied as well as an average figure for all three interpreters. A further understanding of interpretation error is given in Table B. The figures in Table B indicate the number of incorrectly identified trees per species (commission error). These figures were then grouped for each film-filter, scale combination.

All species were most accurately identified on the aerial "Ektachrome film, scale 1/2,500, except for Quercus kelloggii (California black oak) which was most easily identified on Ekta Aero Infrared film, scale 1/5,000. Pinus lambertiana (sugar pine) and Abies concolor (white fir) were the most easily identified species,, while Pinus ponderosa (ponderosa pine), Libocedrus decurrens (incense cedar) and Pseudotsuga menziesii (Douglas fir) were the most difficult species to distinguish.

44R

Table A: Summary of Interpretation Results; Percentage of Correctly Identified Trees (Based on 25 Trees of Each Species)

Interpreter	Pinus lambertiana	Pinus ponderosa	Abies concolor	Pseudotsuga menziesii	Libocedrus decurrens	Quercus kelloggii
AERIAL EKTACHROME, 1/5000						
1	72%*	52%	84%	24%	20%	48%
2	48%	48%	92%	60%	40%	64%
3	68%	40%	96%	36%	48%	48%
Average	62.7%	46.7%	90.7%	40.0%	36.0%	53.3%
EKTA AERO INFRARED, 1/5000						
Interpreter						
1	76%	48%	80%	48%	36%	100%
2	72%	40%	88%	48%	0	100%
3	88%	28%	84%	36%	44%	100%
Average	78.7%	38.7%	84.0%	44%	26.7%	100%
PANCHROMATIC, 1/2500						
Interpreter						
1	96%	40%	60%	36%	4%	92%
2	76%	44%	96%	56%	4%	72%
3	92%	56%	92%	28%	32%	88%
Average	88.0%	46.7%	82.7%	40.0%	13.3%	84%
AERIAL EKTACHROME, 1/2500						
Interpreter						
1	96%	72%	96%	56%	64%	84%
2	100%	80%	88%	60%	80%	80%
3	100%	48%	88%	56%	56%	92%
Average	98.7%	66.7%	90.7%	57.3%	66.7%	85.3%

* 72% of all Pinus lambertiana (sugar pine) present were correctly identified as such by interpreter #1.

Table B: Summary of Interpretation Results; Number of Incorrectly Identified Trees

Inter.	*Pinus lambertiana*	*Pinus ponderosa*	*Abies concolor*	*Pseudotsuga menziesii*	*Libocedrus decurrens*	*Quercus kelloggii*	Total
AERIAL EKTACHROME 1/5000							
1	3*	24	17	10	6	9	69
2	4	2	28	11	11	6	62
3	15	15	12	5	15	7	69
Total	22	41	57	26	32	22	200
EKTA AERO INFRARED, 1/5000							
Inter.							
1	12	18	8	8	5	2	53
2	5	3	11	15	3	26	63
3	16	4	16	11	5	4	56
Total	33	25	35	34	13	32	172
PANCHROMATIC, 1/2500							
Inter.							
1	10	11	20	11	7	9	68
2	5	7	18	24	1	8	63
3	9	11	14	6	7	6	53
Total	24	29	52	41	15	23	184
AERIAL EKTACHROME, 1/2500							
Inter.							
1	7	12	6	3	5	0	33
2	11	6	2	5	4	0	28
3	9	12	7	2	9	1	40
Total	27	30	15	10	18	1	101

* Out of 69 incorrectly identified trees by interpreter #1, three were called *Pinus lambertiana* (sugar pine).

Because of the close similarity between Pinus ponderosa (ponderosa pine) and Libocedrus decurrens (incense cedar) these two species were often confused; however, identification of ponderosa pine and incense cedar as a single group was accurate. Pseudotsuga menziesii (Douglas fir) was extremely difficult to identify because of its variation in form and tone or color. Rather than being confused with any one particular species, Douglas fir was often called sugar pine, ponderosa pine or California black oak.

Table A indicates that Abies concolor (white fir) can be accurately identified on the poorest film-filter scale combination; however, Table B shows that the majority of trees incorrectly identified were called white fir. Therefore, most "border line" trees were generally called white fir which would generate greater accuracy of identification within the white fir group.

Interpretation experience did not seem to affect identification results as was expected. Once the image characteristics of each species had been learned by use of the prepared key, the inexperienced interpreter did as well as the experienced interpreters in identifying species. However, the time required for the inexperienced interpreter to complete the test was approximately three times as long as for the experienced interpreters. Difficulties in handling and viewing the photographs by the inexperienced interpreter caused this difference in time between interpreters.

APPENDIX III - SPECTRAL REFLECTANCE CURVES

SPECTRAL REFLECTANCE OF REPRESENTATIVE TREE SPECIES IN CALIFORNIA FOUND TO OCCUR IN THE CENTRAL SIERRA NEVADA (MIXED CONIFER FOREST TYPE) AND THE COAST RANGE (CHAPARRAL-HARDWOOD FOREST TYPE)

A thorough understanding of light reflectance is necessary when attempting to analyze tonal differences between subjects, in this case tree foliage, on vertical aerial photographs. Image tone is a function of film sensitivity, filter transmittance, atmospheric conditions and percent of light reflectance. In a photographic experiment such as this, film sensitivity and atmospheric conditions are held constant and the manipulation of light transmitting filters allows isolated bands consisting of small portions of the electromagnetic spectrum to be recorded on the film emulsion. A determination as to which film-filter combination might produce maximum contrast between two or more tree types depends directly upon the part or range of the spectrum where maximum differences in foliage reflectance occurs. Once this factor is determined, the filter that will only transmit light from that part of the spectrum can be chosen.

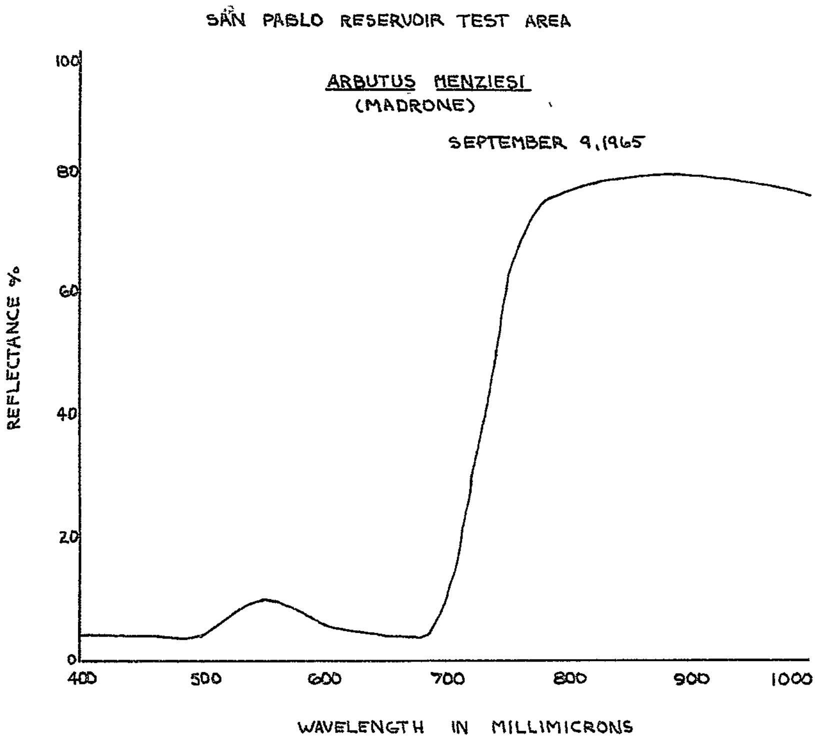
Spectral reflectance measurements were made on foliage samples of representative tree types occurring in the Sierra Nevada (mixed conifer forest type) and the Coast Range (chaparral-hardwood forest type). A General Electric recording spectrophotometer at the University of California Illumination Laboratory was used to make spectrometric readings on samples prepared from each species. This machine graphically records percent light reflectance from 400 millimicrons to 1,000 millimicrons within the spectrum.

Great care was taken in obtaining a representative sample for reading. Three healthy trees of each species were selected at random, each

N4W

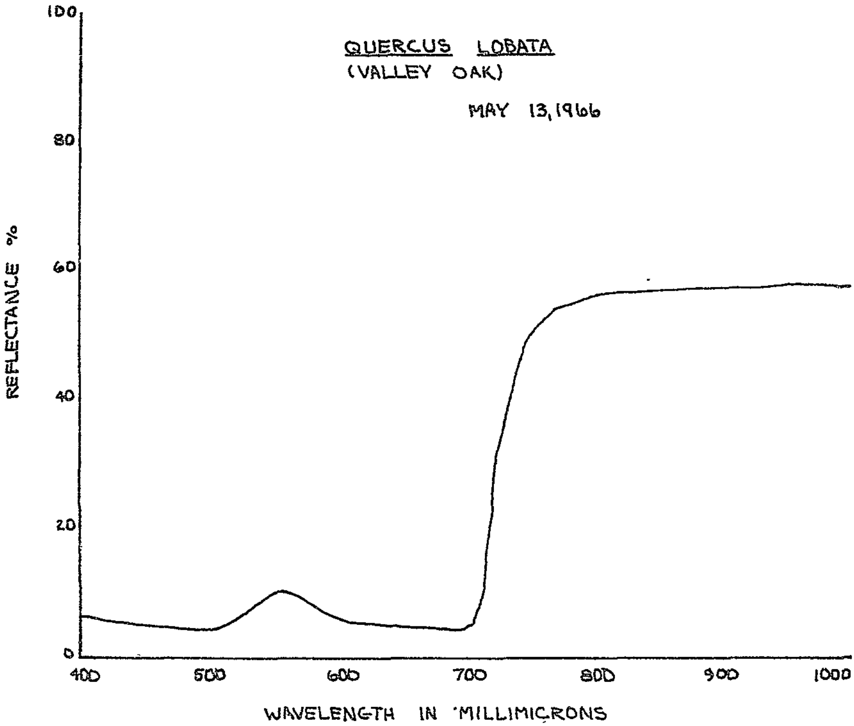
varying in size and age. Three foliage samples, each consisting of a large tuft of needles were cut from the top portion of each tree. Because light reflected from the top portion of a tree is recorded on aerial photographs, an 18-foot "tree trimmer" was used to reach samples high in the tree crown. Once a sample was cut it was placed in a plastic bag, labeled and refrigerated in a portable ice chest in order to prevent excessive evaporation or transpiration losses of water content before the sample could be analyzed with the spectrophotometer. Within a 24 hour period, the sample was placed between two clear glass plates (having spectrally flat transmittance curves) and a reading was made on it by the laboratory spectrophotometer. Care was taken in preparing the sample; needles were oriented so that the top side would be read rather than the bottom side which is generally heavily covered with tiny stomatal openings.

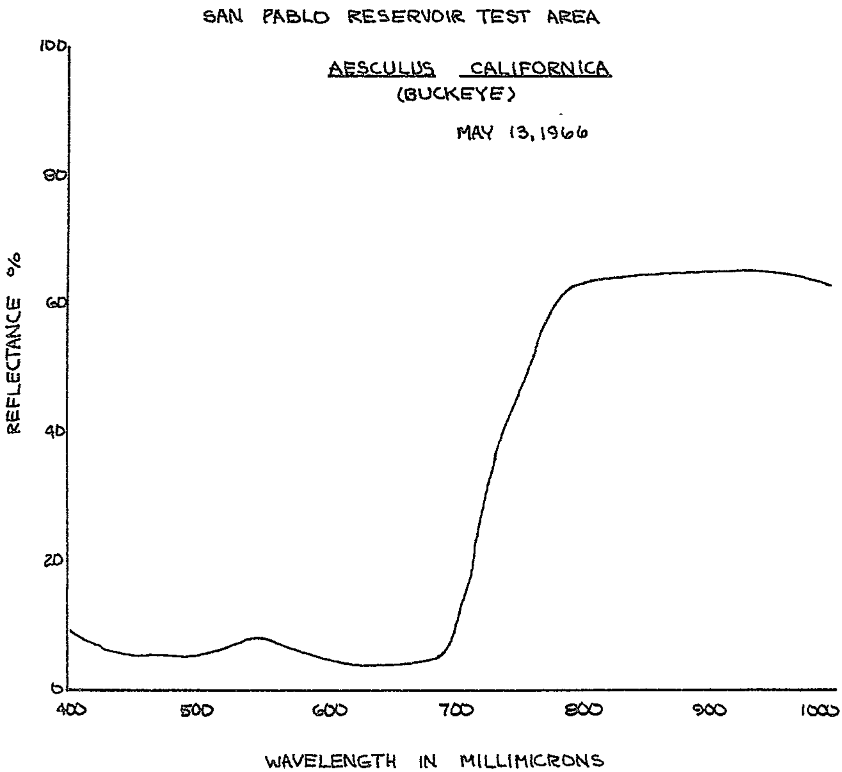
The following graphs represent a summary of the readings made for each species studied and indicate the variation of light reflectance occurring within a particular species. A discussion of conclusions drawn from these reflectance measurements and a statement of the optimum film-filter combinations to be used to capitalize on reflectance differences is on pages 17 to 19 of this report.

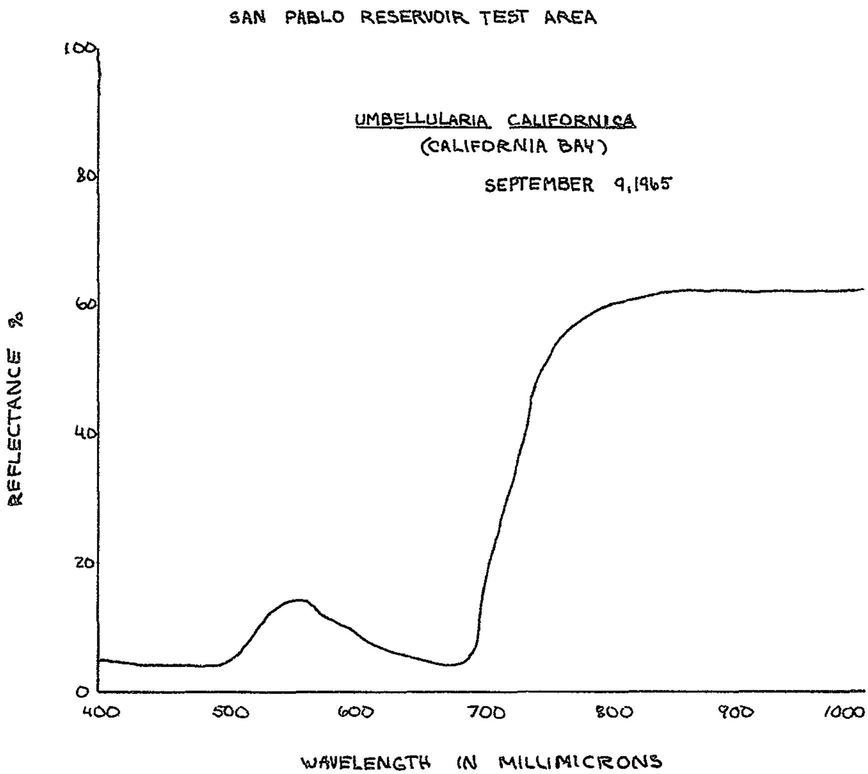

SAN PABLO RESERVOIR TEST AREA
ARBUTUS MENZIESI
(MADRONE)
SEPTEMBER 9, 1965
REFLECTANCE %
0
20
40
60
80
100
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS

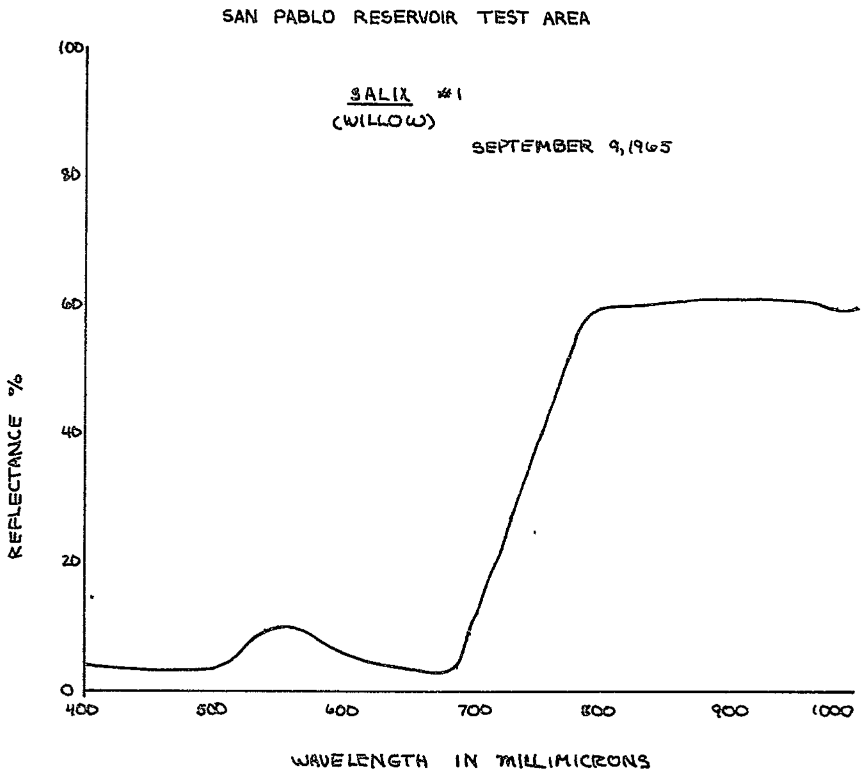
HH4

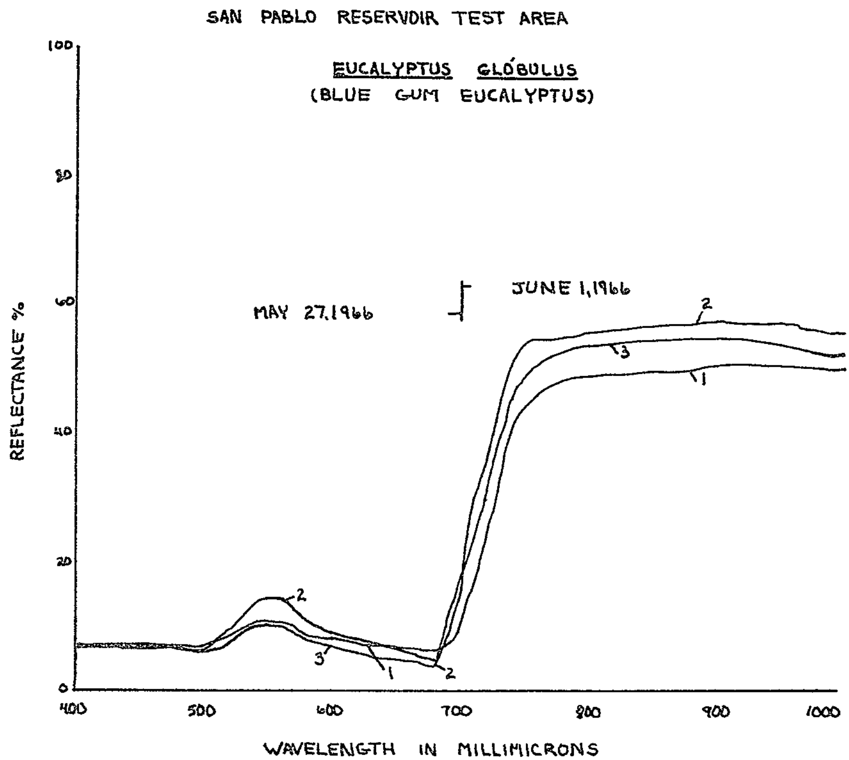
SAN PABLO RESERVOIR TEST AREA




SAN PABLO RESERVOIR TEST AREA
AESCULUS CALIFORNICA
(BUCKEYE)
MAY 13, 1966
REFLECTANCE %
100
80
60
40
20
0
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS


SAN PABLO RESERVOIR TEST AREA
UMBELLULARIA CALIFORNICA
(CALIFORNIA BAY)
SEPTEMBER 9, 1965
REFLECTANCE %
100
80
60
40
20
0
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS

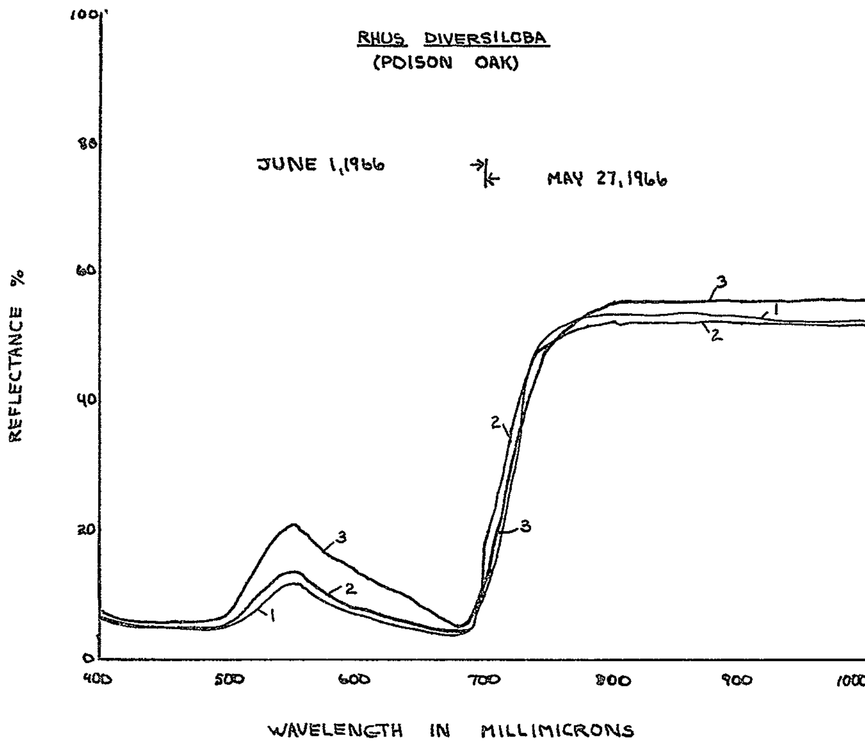

SAN PABLO RESERVOIR TEST AREA
SALIX #1
(WILLOW)
SEPTEMBER 9, 1965
100
80
60
40
20
0
REFLECTANCE %
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS



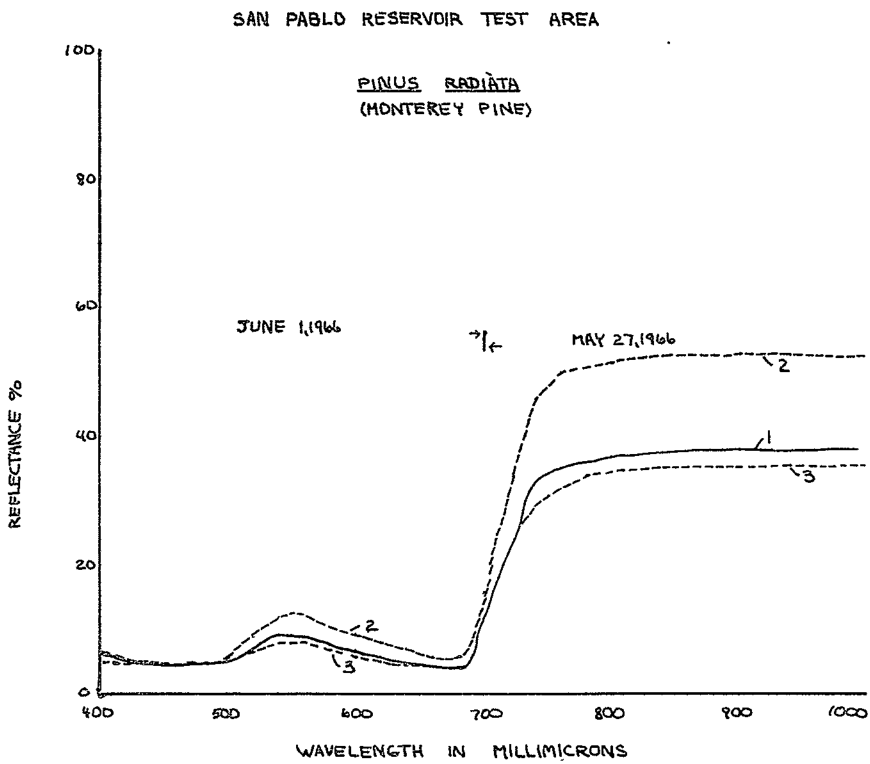
SAN PABLO RESERVOIR TEST AREA
EUCALYPTUS GLÓBULUS
(BLUE GUM EUCALYPTUS)
MAY 27,1966
JUNE 1,1966
REFLECTANCE %
WAVELENGTH IN MILLIMICRONS
100
80
60
40
20
0
400
500
600
700
800
900
1000
1
2
3

45R

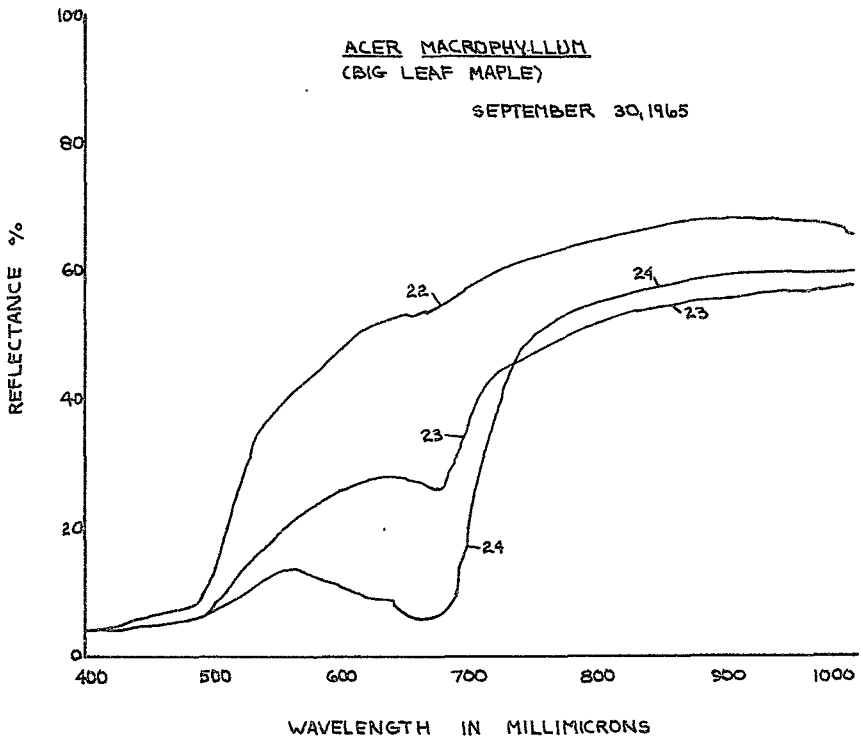
SAN PABLO RESERVOIR TEST AREA

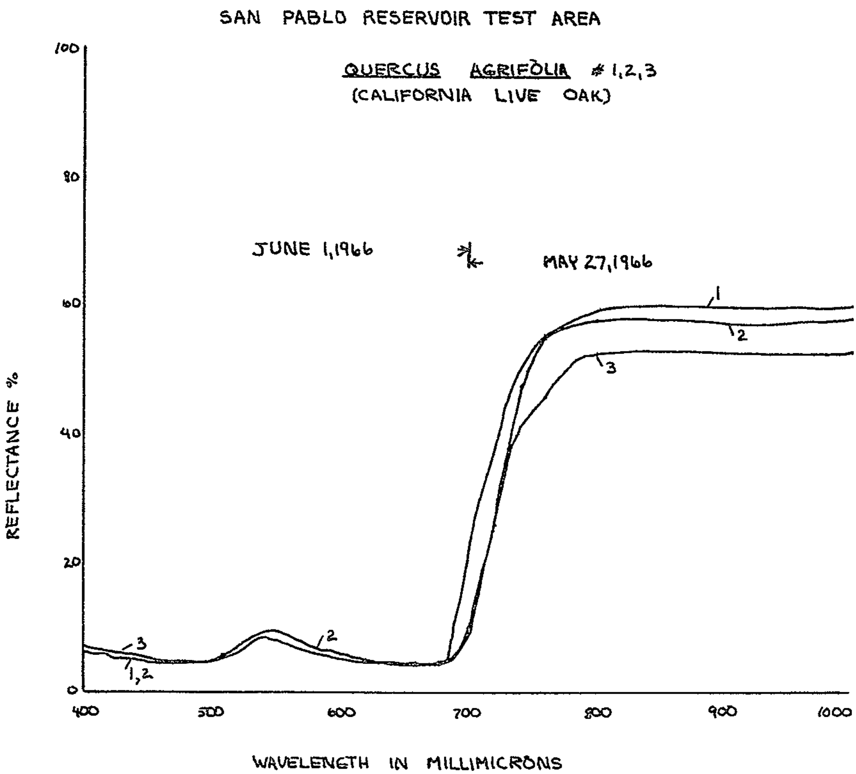


45K

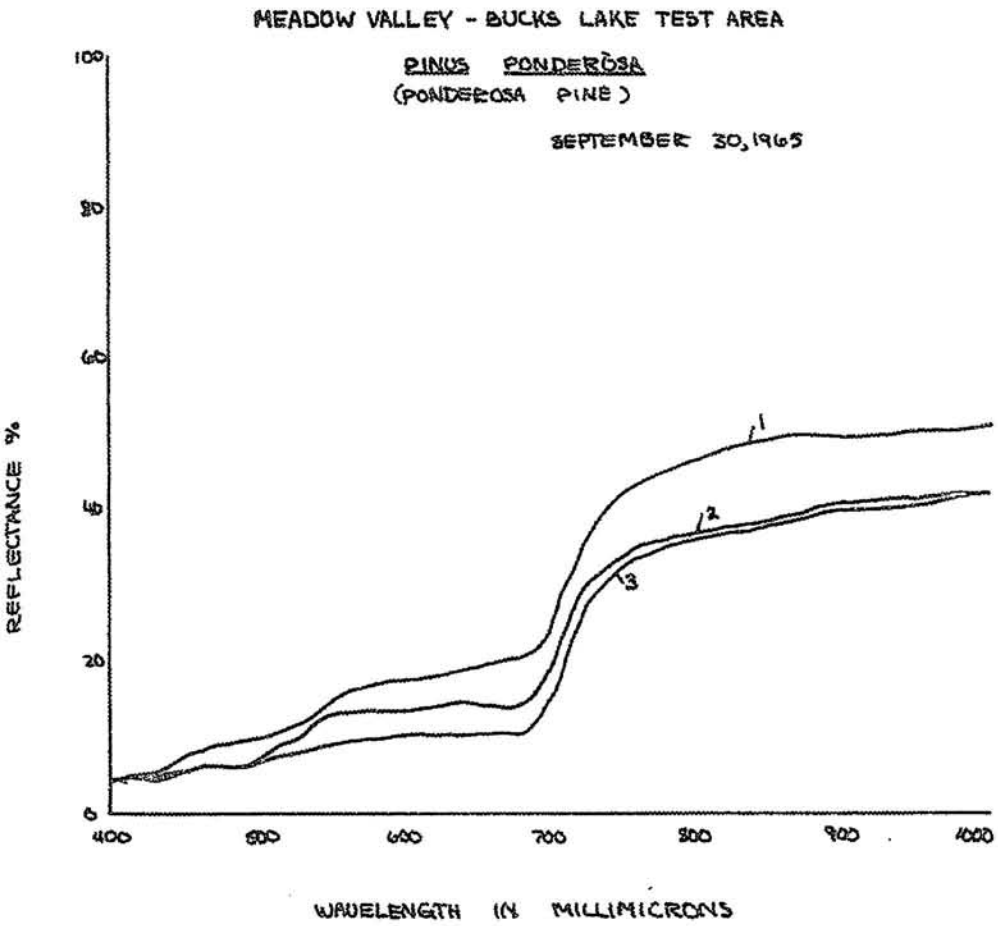

SAN PABLO RESERVOIR TEST AREA
PINUS RADIÀTA
(MONTEREY PINE)
JUNE 1,1966
MAY 27,1966
REFLECTANCE %
WAVELENGTH IN MILLIMICRONS
100
80
60
40
20
0
400
500
600
700
800
900
1000
1
2
3

SAN PABLO RESERVOIR TEST AREA

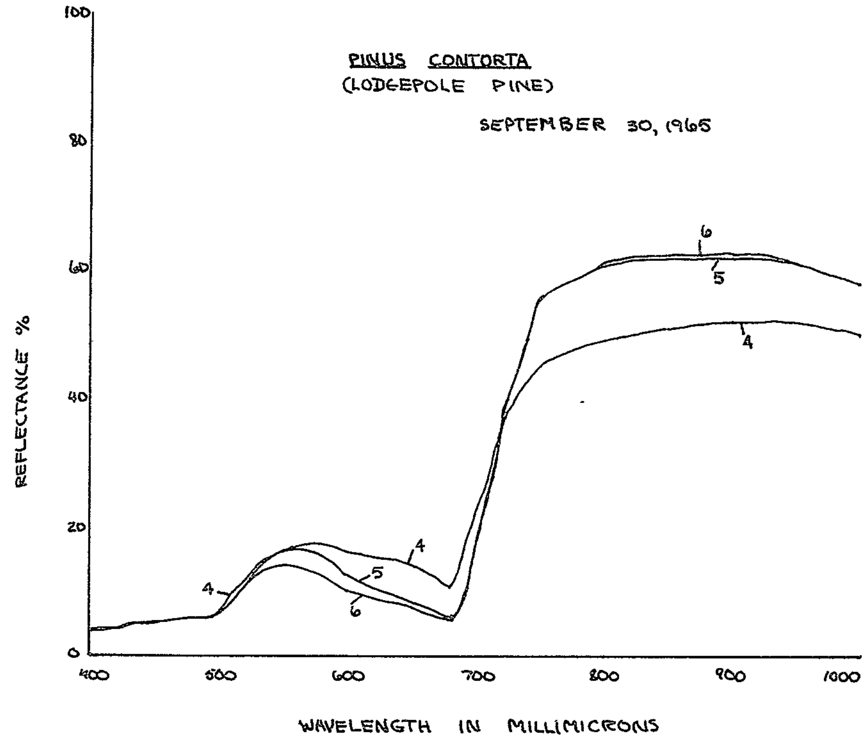


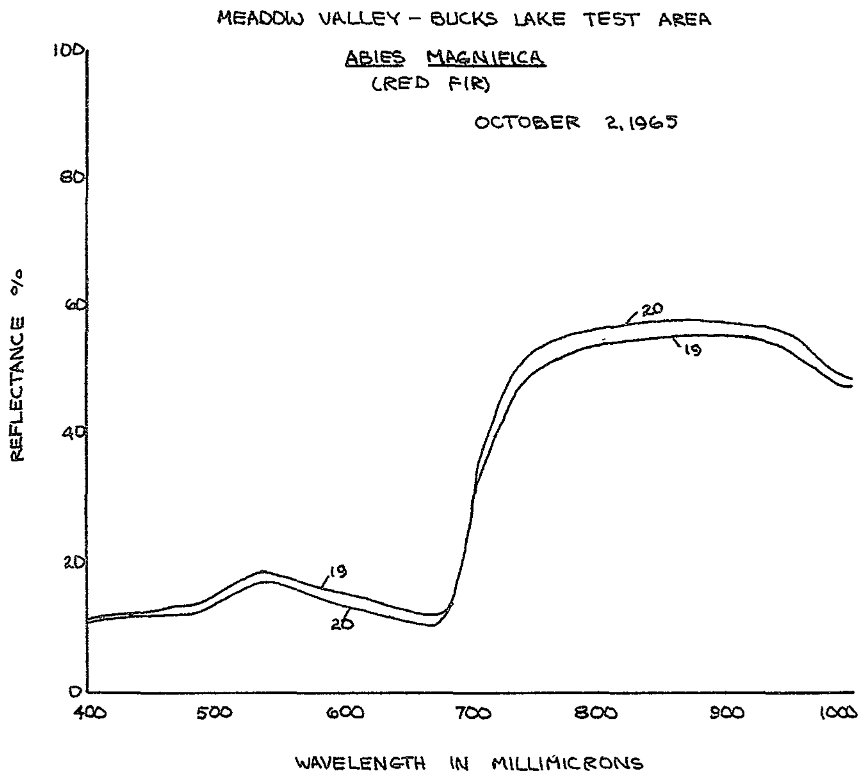


SAN PABLO RESERVOIR TEST AREA
QUERCUS AGRIFOLIA #1,2,3
(CALIFORNIA LIVE OAK)
JUNE 1,1966
MAY 27,1966
REFLECTANCE %
WAVELENGTH IN MILLIMICRONS
0
20
40
60
80
100
400
500
600
700
800
900
1000
1
2
3
1,2

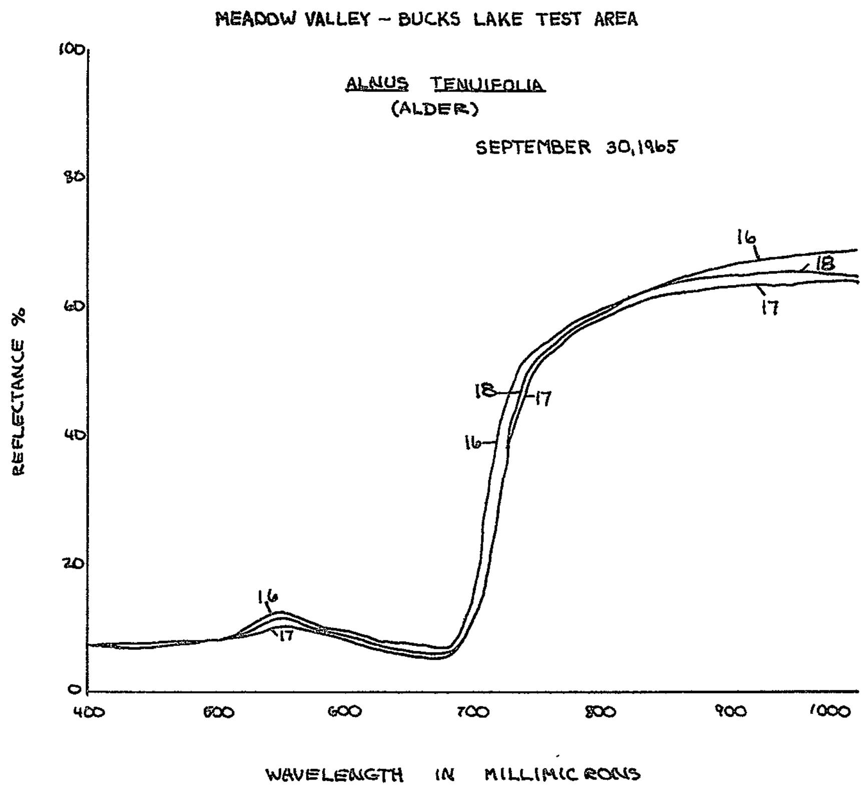

MEADOW VALLEY - BUCKS LAKE TEST AREA
PINUS PONDEROSA
(PONDEROSA PINE)
SEPTEMBER 30, 1965
REFLECTANCE %
100
80
60
40
20
0
400
500
600
700
800
900
1000
1
2
3
WAVELENGTH IN MILLIMICRONS

MEADOW VALLEY - BUCKS LAKE TEST AREA

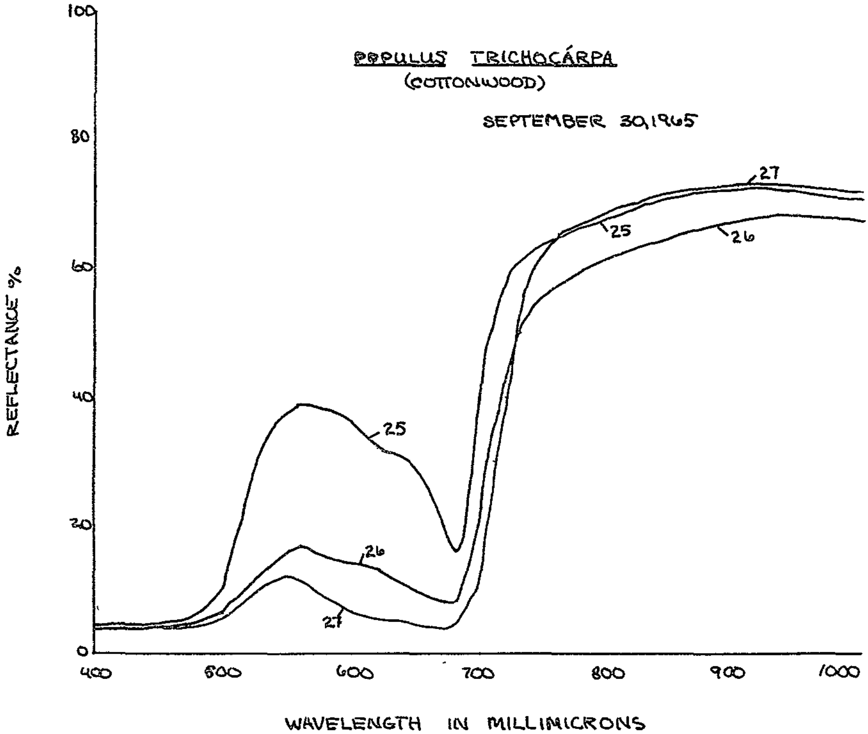


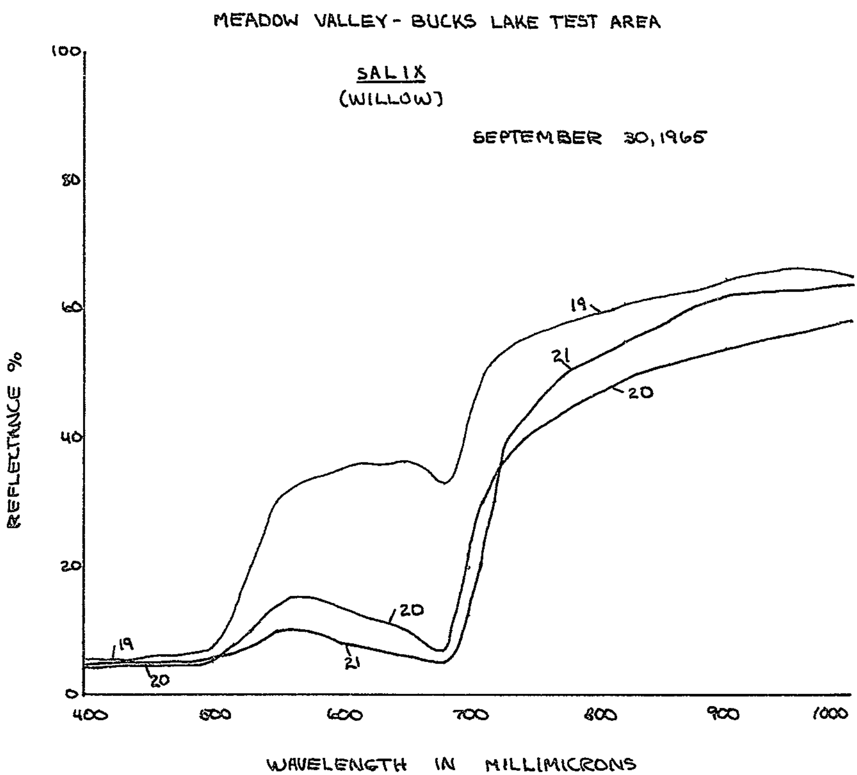

MEADOW VALLEY - BUCKS LAKE TEST AREA
ABIES MAGNIFICA
(RED FIR)
OCTOBER 2, 1965
REFLECTANCE %
100
80
60
40
20
0
19
20
20
19
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS

45K

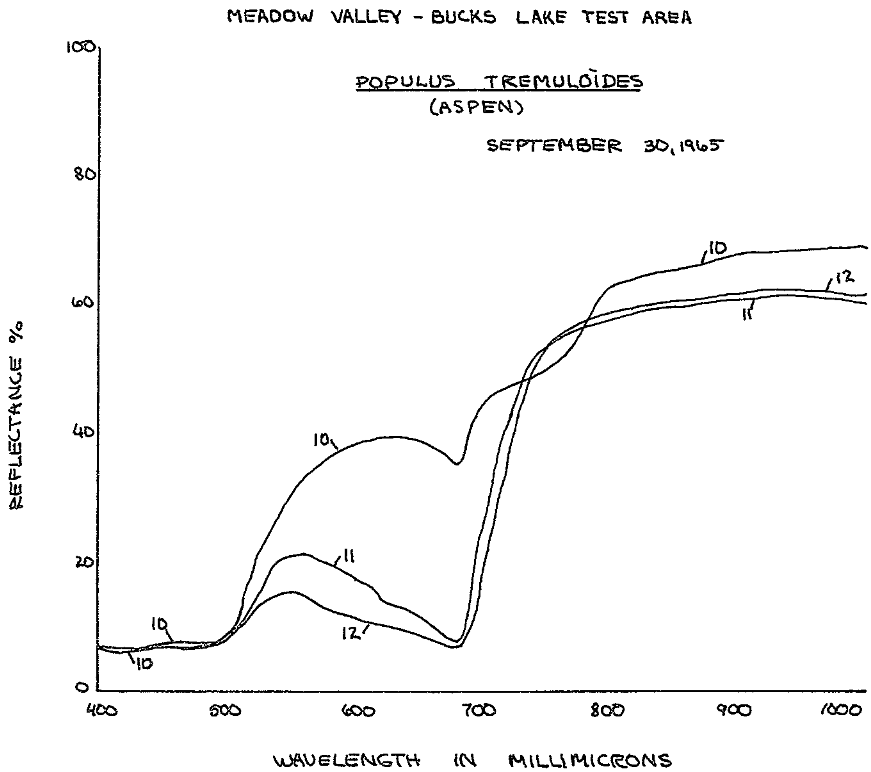

MEADOW VALLEY – BUCKS LAKE TEST AREA
ALNUS TENUIFOLIA
(ALDER)
SEPTEMBER 30, 1965
REFLECTANCE %
100
80
60
40
20
0
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS
16
17
18

MEADOW VALLEY - BUCKS LAKE TEST AREA

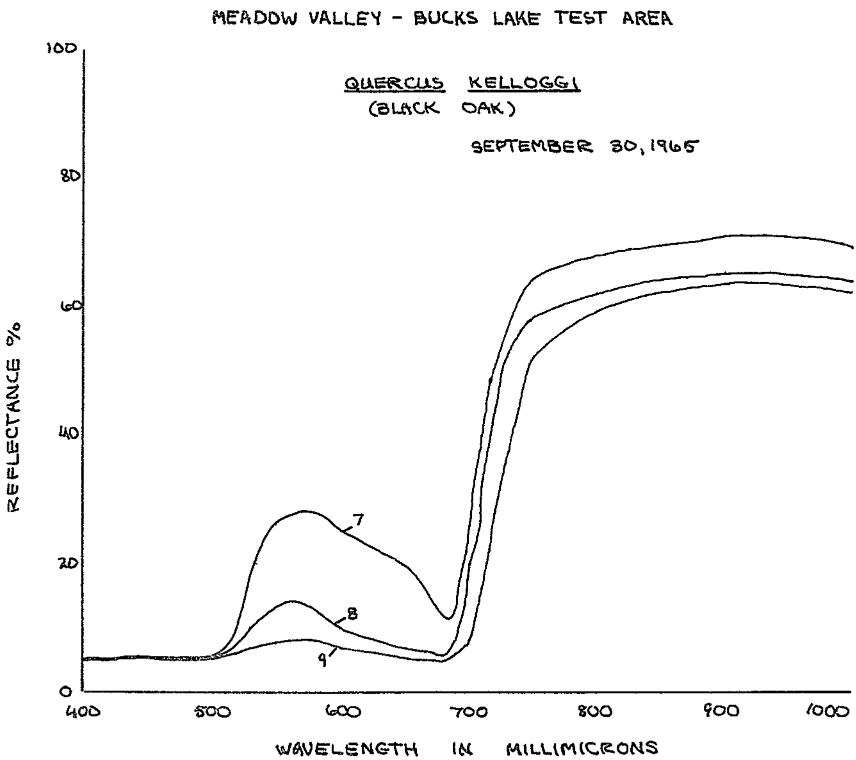



MEADOW VALLEY - BUCKS LAKE TEST AREA
SALIX
(WILLOW)
SEPTEMBER 30, 1965
REFLECTANCE %
WAVELENGTH IN MILLIMICRONS
0
20
40
60
80
100
400
500
600
700
800
900
1000
19
20
21

45N



MEADOW VALLEY - BUCKS LAKE TEST AREA
POPULUS TREMULOIDES
(ASPEN)
SEPTEMBER 30, 1965
REFLECTANCE %
0
20
40
60
80
100
400
500
600
700
800
900
1000
WAVELENGTH IN MILLIMICRONS
10
11
12


MEADOW VALLEY - BUCKS LAKE TEST AREA
QUERCUS KELLOGGI
(BLACK OAK)
SEPTEMBER 30, 1965
REFLECTANCE %
WAVELENGTH IN MILLIMICRONS
0
20
40
60
80
100
400
500
600
700
800
900
1000
7
8
9

MEADOW VALLEY - BUCKS LAKE TEST AREA